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Problem Definition Study on Techniques and Methodologies for Evaluating the Chemical and Toxicological Properties of Combustion Products of Gun Systems, Vol. 2:

Facility Criteria for the Chemical and Toxicological Characterization of Gun Exhaust

Final Report

January, 1989

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Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, MD 21701-5012
Army Project Order No. 85PP5840

Oak Ridge National Laboratory
Oak Ridge, TN 37831-6120

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DEPARTMENT OF ENERGY

AD-A205447

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Analytical Chemistry Division Oak Ridge National Laboratory 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U.S. Army Biomedical Research and Development Laboartory
6c. ADDRESS (City, State, and ZIP Code) Building 4500-S P.O. Box 2008 Oak Ridge, TN 37831-6120	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21701-5010
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Medical Research & Development Command 8b. OFFICE SYMBOL (If applicable) SGRD-RMI-S	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER APO #85PP5840
8c. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, Maryland 21701-5012	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62787A	3E1-62787A	CA	301

11. TITLE (Include Security Classification) Problem Definition Study on Techniques and Methodologies for Evaluating the Chemical and Toxicological Properties of Combustion Products of Gun Systems, Vol 2: Facility Criteria for the Chemical and Toxicolcgical Characterization of Gun Exhaust.

12. PERSONAL AUTHOR(S)
Jenkins, R. A., Moneyhun, J. H., Gayle, T. M., Lore, j. D., and Ross, R. H.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ____ TO ____	1989 January	69

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
06	11	
06	14	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Ammunition, aerosols, analytical chemistry, cannon, chemical characterization, combustion products, criteria, facility, gun, gun exhaust, inhalation exposure, (cont'd)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The exhaust produced from the firing of rifles, cannons, and large guns is an exceedingly complex mixture of gases, organic vapor and particle phase constituents, and inorganic species. Although the rifle and gun are ubiquitous to the military, information about the chemical and toxicological properties of the weapons exhaust mixture is limited. This is so, in part, because laboratory duplication of the gun environment, particularly for large-caliber weapons, is a largely untested but inherently complex task. The purpose of this report is to define the criteria for a facility dedicated to the controlled generation, chemical and physical characterization, and toxicological evaluation of weapons produced exhaust.

A number of approaches to the generation of gun exhaust in a controlled fashion were evaluated. These included the firing of actual weapons, both large and small, the firing of downsized or real guns using scaled down ammunition to simulate the firing of larger guns, the use of gun simulators and closed bombs, the use of small weapon (continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☑ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Mary Francis Bostian	22b. TELEPHONE (Include Area Code) (301) 663-7325 22c. OFFICE SYMBOL SGRD-RMI-S

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

18. Subject Terms (continued)
Methodology, monitoring, propellants, rifle, toxicology.

19. Abstract (continued)

exhaust supplemented with toxic gases to simulate a larger weapon, and the use of a synthetic aerosol of toxic gases and particulates. The recommended approach is to generate the exhausts using two guns. A smaller rifle would be used to generate the products from single base propellants, and a 30 mm cannon firing munitions which would be scaled down versions of those in larger guns would be used to generate near-real exhaust. The exhaust collection and distribution system which would surround the gun generator is designed to provide a continuous concentration of diluted exhaust for chemical and toxicological evaluation, despite the fact that the firing is inherently a discrete event.

A description of the methods for chemical species which would be determined in real time is provided. Additional considerations in the areas of projectile containment, noise abatement, toxicological evaluations, safeguards and security, siting requirements, and technical staff to support such a facility are discussed.

ORNL-6334/V2

PROBLEM DEFINITION STUDY ON TECHNIQUES AND METHODOLOGIES FOR EVALUATING THE CHEMICAL AND TOXICOLOGICAL PROPERTIES OF COMBUSTION PRODUCTS OF GUN SYSTEMS, VOL. 2:

Facility Criteria for the Chemical and Toxicological Characterization of Gun Exhaust

FINAL REPORT

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Under Contract No. DE-AC05-84OR21400

EXECUTIVE SUMMARY

Rifles and large-caliber guns generate exhaust emissions as a result of combustion of propellant mixtures. Combustion occurs under high temperature and pressure inside the gun until the projectile is ejected from the barrel. Chemical transformations continue to occur after the gases are ejected from the muzzle. The resulting exhaust emissions are a complex mixture of chemical species. The rifle and gun are ubiquitous to the military. Every soldier is likely to receive some exposure to the exhaust products. Unfortunately, information about the chemical and toxicological properties of the weapons exhaust mixture is limited. This is so, in part, because laboratory duplication of the gun environment, particularly for large-caliber weapons, is an untested but inherently complex task. In order to efficiently focus research efforts, a two phase study was initiated. In the first phase, a literature evaluation of techniques and methodologies was undertaken. In this, the second phase, the criteria for a facility dedicated to the controlled generation, chemical and physical characterization, and toxicological evaluation of weapons produced exhaust are defined.

A review of the literature indicated that:

1. The composition of gun exhaust is exceedingly complex, and that it will depend on the composition of the munition charge and the variation of temperature and pressure with time in the gun barrel.

2. The material present in the exhaust is not likely to be at equilibrium when it exits the gun barrel.

3. There exist chemically important differences between the composition of breech and muzzle exhaust, and since troops are likely to be exposed to both, both must be evaluated.

These findings provided the basis for the determination of the likely feasibility of a gunsmoke facility. Next, preliminary desirable criteria for such a facility were developed, followed by consultation with experts and further literature review. Finally, the information and recommendations were distilled and synthesized to form the basis of this report.

A number of scientifically defensible approaches to the generation of gun exhaust in a controlled fashion were evaluated. These included the firing of actual weapons, both large and small, the firing of downsized or real guns using scaled down ammunition to simulate the firing of larger guns, the use of gun simulators and closed bombs, the use of small weapon exhaust supplemented with toxic gases to simulate a larger weapon, and the use of a synthetic aerosol of toxic gases and particulates. Each of the options has its advantages and disadvantages. The firing of real or downsized guns offers the considerable advantages of a realistic exposure atmosphere to characterize chemically and toxicologically. However, this approach has the disadvantages of noise and a requirement to stop a high energy projectile. A gun simulator has the advantage of a "contained" projectile. However, simulators in existence have been designed for occasional firings, and not repeated use, as would be the case in an inhalation exposure situation. Closed bombs also offer the advantage of no projectile. However, because the temperature and pressure functionality is so different from that of an actual firing of a gun, the degree to which such a system can accurately simulate a real gun is questionable. And the approach in which mixtures of major and minor constituents are used does not appear to sufficiently mimic the real exhausts to be worthwhile pursuing.

Thus, the recommended approach was to generate the exhausts using two guns. A smaller rifle would be used to generate exhaust products from single base propellants, and a 30 mm cannon firing munitions which would be scaled down versions of those in larger guns would be used to generate near-real exhaust. The exhaust collection and distribution system which would surround the gun generator is described in detail, and is designed to provide a continuous concentration of diluted exhaust for chemical and toxicological evaluation, despite the fact that the firing is inherently a discrete event. It accomplishes this by firing the round through two valves at either end of the exhaust collection chamber, into which is flushed the breech exhaust. The round is trapped by either a commercial bullet catcher or a sand bag trap. The contents of the collection chamber are drawn through a proportioning valve, which is regulated by a real time measurement of carbon monoxide downstream of the valve. This compensates for the dilution of the remaining exhaust which occurs as the collection chamber is emptied. A fraction of the exhaust is retained in a small, collapsible chamber, so that animals can be exposed to continuous exhaust when the main system is being recycled and readied for the next firing sequence.

The major chemical species which would be determined in real time for chemical characterization studies include carbon monoxide, carbon dioxide, methane, ammonia, hydrogen, oxides of nitrogen and hydrogen cyanide. Provisions for collection of organic vapor phase and particle phase constituents are described, as well as those for inorganic species and particle size distribution determination.

Important considerations for the toxicological evaluation studies include the degree of exhaust aging which will be considered acceptable and the degree to which whole body inhalation exposures can be used when determining the toxicity of breech-only exhaust. In terms of siting of the facility, perceived safety of the facility will be a major concern, and it seems likely that the over-chamber in which the system is installed must be constructed so as to contain a catastrophic failure of the system. If the system is used for routine exposures or large number of animals, then the eventual placement of the facility at a specific institution may depend on the space and facilities for storing significant quantities of ammunition. It seems likely that the need to perform both chemical and biological studies will limit the siting options to relatively large multidisciplinary research institutions, either in the private or public sector.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to all of those individuals who provided their expert insight, analysis, and comments on the concepts that provided the basis for this assessment. These individuals included T. Daniels, Hercules, Inc., of the Radford Army Ammunition Plant, John Domen, R. Trifiletti and the late Ludwig Steifel. of the Army Armament Engineering Directorate, Craig Herud, of Aberdeen Proving Ground, Stephen Hanchak, of the Impact Physics Group, University of Dayton Research Institute, P. Lilienfeld, of GCA Corporation, Merle Paule, of the National Center for Toxicological Research, and Bill VonHalle, of Lawrence Livermore National Laboratory.

Thanks are due to Major David Parmer, Contracting Officers Representative, U. S. Army Biomedical Research and Development Laboratory, (ABRDL), Fort Detrick, Frederick, Maryland, and to other ABRDL staff for their support, patience, and helpful technical review of this work.

The authors are especially appreciative of Ramona Williams, Odie Costanzo, and Pat Trentham for their assistance in document preparation and organization of reference materials.

DISCLAIMER

CONTENTS

1. INTRODUCTION AND BACKGROUND 11

1.1 PURPOSE AND MILITARY OBJECTIVES 11
1.2 LITERATURE REVIEW APPROACH 11

2. LITERATURE REVIEW OF GENERATION SYSTEMS PREVIOUSLY TRIED WHICH INVOLVE FIRING OF MUNITIONS 14

2.1 INTRODUCTION 14
2.2 CLOSED BOMB EXHAUST GENERATORS 14
2.3 GUN SIMULATORS 14
2.4 FIELD SAMPLING AND ANALYSIS 15
2.5 SMALL ARMS FIRING WITHIN ENCLOSURES 15

3. DESIGN OBJECTIVES, CRITERIA, AND LIMITATIONS 17

3.1 INTRODUCTION 17
3.2 CRITERIA FOR THE GUNSMOKE GENERATION PHYSICAL/CHEMICAL CHARACTERIZATION FACILITY ... 17

3.2.1 Number of Generation Systems 17
3.2.2 Collection and Distribution Systems 17
3.2.3 Operator Intervention 18
3.2.4 Safety Considerations 18
3.2.5 Engineering Flexibility 18

3.3 CRITERIA FOR THE TOXICOLOGICAL CHARACTERIZATION FACILITY 18

3.3.1 Toxicologic Evaluation Flexibility 19
3.3.2 Live Animal Considerations 19

3.4 FACILITY LIMITATIONS 19

3.4.1 Limiting Toxic Constituents 19
3.4.2 Firing Noise 20
3.4.3 Firing Rate Limitations 20
3.4.4 Spent Projectile Handling 20
3.4.5 Acquisition of Down-Sized Ammunition 20
3.4.6 Safeguards and Security Issues 21
3.4.7 Specialized Staffing Requirements 21

4. EVALUATION AND COMPARISON OF ALTERNATE APPROACHES 22

4.1 INTRODUCTION 22
4.2 FIRING OF ACTUAL WEAPONS 22
4.2.1 Description 22
4.2.2 Advantages of Approach 22
4.2.3 Disadvantages of Approach 23
4.2.4 Cost 23
4.2.5 Feasibility 23

4.3 FIRING OF DOWNSIZED GUNS USING SCALED DOWN AMMUNITION 24

4.3.1 Description 24
4.3.2 Advantages of Approach 24
4.3.3 Disadvantages of Approach 24
4.3.4 Costs 25
4.3.5 Feasibility 25

4.4 FIRING OF GUN SIMULATORS 25

4.4.1 Description 25
4.4.2 Advantages of Approach 26
4.4.3 Disadvantages of Approach 26
4.4.4 Costs 26
4.4.5 Feasibility 27

4.5 CLOSED BOMB FOR GENERATING SIMULATED GUNSMOKE EXHAUST 27

4.5.1 Description 27
4.5.2 Advantages of Approach 27
4.5.3 Disadvantages of Approach 27
4.5.4 Costs 28
4.5.5 Feasibility 28

4.6 SMALL WEAPON EXHAUST PLUS ADDED TOXIC GASES TO SIMULATE A LARGE WEAPON 28

4.6.1 Description 28
4.6.2 Advantages of Approach 29
4.6.3 Disadvantages of Approach 29
4.6.4 Costs 29
4.6.5 Feasibility 30

4.7 SIMULATION OF LARGE AND SMALL GUN EXHAUST USING AN AEROSOL OF MIXED GASES AND PARTICULATES ... 30

4.7.1 Description ... 30
4.7.2 Advantages of Approach ... 30
4.7.3 Disadvantages of Approach ... 30
4.7.4 Costs ... 30
4.7.5 Feasibility ... 31

4.8 SUMMARY AND RECOMMENDATIONS ... 31

5. RECOMMENDED FACILITY CRITERIA AND FEATURES ... 32

5.1 INTRODUCTION AND PURPOSE ... 32

5.2 GENERATION SYSTEMS ... 32

5.2.1 Fixed Mount Small Rifle ... 32
5.2.2 30 mm Cannon ... 33

5.3 EXHAUST COLLECTION AND DISTRIBUTION SYSTEM (CDS) ... 33
5.3.1 Introduction ... 33
5.3.2 Breech Assembly ... 35
5.3.3 Main Exhaust Collection System ... 37
5.3.4 Bullet Catching Region ... 39
5.3.5 Bag Containment System ... 39
5.3.6 Exhaust Proportioning System and Firing Programmer ... 40
5.3.7 Example Firing Sequences ... 42

5.4 SCALED-DOWN AMMUNITION FOR 30 MM GENERATION SYSTEM ... 44

5.5 SAMPLING AND ON-LINE ANALYSIS SYSTEMS FOR CHEMICAL CHARACTERIZATION STUDIES ... 45

5.5.1 Introduction ... 45
5.5.2 Reactive and Low Molecular Weight Gases and Vapors ... 45
5.5.3 Organic Vapor Phase Constituents ... 47
5.5.4 Organic Particle Phase Constituents ... 47
5.5.5 Inorganic Particle Phase Constituents ... 48
5.5.6 Particle Size Determination Instrumentation ... 48

5.6 INSTRUMENTATION FOR ROUTINE GENERATION OR EXPOSURE MONITORING ... 49

5.7 TOXICOLOGICAL CHARACTERIZATION CONSIDERATIONS 50

5.7.1 Introduction and Purpose 50
5.7.2 Inhalation Exposure of Live Animals 50

5.7.2.1 Degree of Exhaust Aging Suitable for Exposure 50
5.7.2.2 Utility of Nose-Only vs. Whole Body Exposure for Rodents 51
5.7.2.3 Consideration for Larger Animals 51

5.7.3 Non-Inhalation Toxicological Study Considerations 52

5.8 PROJECTILE CONTAINMENT 53

5.9 NOISE ABATEMENT 54

5.10 SAFEGUARDS AND SECURITIES ISSUES 55

5.10.1 Catastrophic Failure of the Gun System 55
5.10.2 Gun and Ammunition Security 56
5.10.3 Siting Considerations Related to Safety Issues 56

5.11 DISPOSAL OF SPENT EXHAUST ATMOSPHERES 56

5.12 TECHNICAL STAFF REQUIREMENTS 57

6.0 REFERENCES 59

APPENDIX A: Suggested Suppliers for Selected System Components 65

LIST OF FIGURES

Figure Page

1. Schematic Diagram of Gun Exhaust Collection and Distribution System 34

2. Schematic Diagram of Breech Spent Cartridge Purging System 36

3. Schematic Diagram of Firing Controller and Proportioning System 40

1. INTRODUCTION AND BACKGROUND

1.1 PURPOSE AND MILITARY OBJECTIVES

Rifles and large-caliber guns generate exhaust emissions as a result of combustion of propellant mixtures. Combustion occurs under high temperature and pressure inside the gun until the projectile is ejected from the barrel. Chemical transformations continue to occur after the gases are ejected from the muzzle. The exhaust emissions are a complex mixture of chemical species, similar in many respects to other exhaust emissions (e.g., diesel exhaust and tobacco smoke) in terms of complexity, but also probably in terms of potential threat to human health.

The rifle and gun are ubiquitous to the military. Every soldier has ~~had~~ some exposure to weapons exhaust products and some receive almost daily exposure. When the exhaust is discharged into the enclosed space of an armored vehicle, a soldier can be expected to inhale significant quantities of the material prior to its removal through the ventilating system. Even when the gun is fired in open space, muzzle exhaust can drift back over the operators and contaminate their breathing space.

Unfortunately, information about the chemical and toxicological properties of the weapons exhaust mixture is limited. This is so, in part, because laboratory duplication of the gun environment, particularly for large-caliber weapons, is an untested but inherently complex task. In order to efficiently focus research efforts, a two phase study was initiated. In the first phase, a literature evaluation of techniques and methodologies was undertaken. In this, the second phase, the criteria for a facility dedicated to the controlled generation, chemical and physical characterization, and toxicological evaluation of exhaust produced by weapons are defined.

In this second phase of the study, emphasis was placed on the very pragmatic issues of how might such a facility be designed, what capabilities would be most appropriate, the practical aspects of and arrangements for generating exhaust products in a controlled manner and collecting them for both <u>in vivo</u> and <u>in vitro</u> toxicologic studies, and safeguards and security issues. Criteria for an example gun generation system will be specified, and the design for an example collection system will be described. Two areas considered to be outside the scope of this report are the specific design for the loading, firing, and barrel mechanism for the recommended gun sub-system for generation, and description of generic toxicologic evaluation facilities.

1.2 LITERATURE REVIEW APPROACH

A thorough review of the existing literature on the chemical and toxicological properties of the combustion products of rifle and gun firings is the subject of Volume 1 of this report (Ross, et al, 1988), and thus will not be reiterated in this, the second volume of the report. However, some important findings and recommendations were made as a result of that study, which bear on the direction taken in this second volume. These are as follows:

1. The composition of gunsmoke (a term to be used generically to describe exhaust products from rifles, small or light arms, and larger guns) is exceedingly complex. It is comprised of a number of relatively low molecular weight gases, organic vapor phase constituents, inorganic based particulates, and higher molecular weight organic species which may be adsorbed on inorganic particulate matter or present as aerosol droplets.

2. The composition of the exhaust products will depend on the composition of the munition charge. There are basically three types of charge formulations: single, double, and triple base. However, there exist a number of different variations of these formulations, and with variation in additives and specific grain sizes and burning pressures, the number of combinations of exhaust compositions is probably limited only by the number of munition types and uses.

3. The material present in the exhaust is not likely to be at equilibrium when it exits the gun barrel. Rapid oxidation occurs during muzzle flash. Changes in chemical composition are likely to occur over longer time periods. For example, nitric oxide (NO) will continue to react with atmospheric oxygen to produce nitrogen dioxide (NO_2). Other gases may continue to react with organic vapor phase constituents as time passes. This reactivity must be taken into account when planning toxicological studies, in order to avoid testing material which has artifactually high or low concentrations of a toxic chemical.

4. Perhaps the most important finding to come from Volume 1 as it relates to determining the criteria for a facility to perform chemical and toxicological evaluations of gunsmoke is that the composition of the exhaust is dependent on the variation of temperature and pressure with time in the gun barrel. As a result, it is likely that the generation of a chemically and toxicologically relevant exhaust requires the firing of a near-real gun system.

5. There exist chemically important differences between the composition of breech and muzzle exhaust, and since troops are likely to be exposed to both, both must be evaluated.

The findings of Volume 1 formed the basis for a determination of the feasibility of a facility for chemical and toxicological evaluation of gunsmoke, as well as the criteria for such a facility. Literature was then reviewed for information as to the specifics of design considerations and criteria for a generation system. For example, although there exists an incredibly wide array of munition propellant formulations, and thus a wide variety of exhaust compositions, thermodynamic considerations and thrust requirements constrain the volume of gases produced to be between 800 and 1000 L per kilogram of propellant fired (Ross, et al, 1988). This in turn constrains the potential size of any dilution system used to deliver gun exhaust products to animals for inhalation exposure.

Next, we contacted a number of experts and manufacturers in the field of gun and munition systems and held phone discussions with them. Because resources for the overall criteria establishment were limited, judicious use of those resources dictated that we limit on-site discussions and inspections to those facilities and individuals which seemed particularly promising. ORNL staff visited the facilities of Mr. Ludwig Stiefel, of the U.S. Army Armament Research and Development Center, Picatinny Arsenal, Dover, New Jersey, Mr. Craig Herud, of the U.S. Army Combat Systems Test Activity, Chemistry Branch, Aberdeen Proving Ground, Maryland, and Dr. Stephen Hanchak, of the Impact Physics Group, University of Dayton Research Institute, Dayton, Ohio. In-house experts within the U.S. Department of Energy facilities at Oak Ridge, Tennessee were consulted as to such issues as facility siting requirements, spent projectile interception, safeguards and security, and collection and distribution of the exhaust products. It became clear, during the discussions with the outside experts, that the design of the 30 mm gun sub-system appeared to be technologically achievable, but it would be outside the scope of this study. Unless a commercially-available design were to be chosen, that portion of the project would consume more resources than had been allocated for all of Phase II of the study. Thus, the goal of that part of the report which focused on the gun sub-system of the exhaust generation and delivery system was directed toward the determination of the criteria which such a gun sub-system would be designed to meet. Once the criteria for the gun sub-system were established, the design for the generation system was developed. Radford Army Ammunition plant was approached as to cost estimates for the downsized ammunition required for part of the project. However, it was indicated to us that resources beyond those remaining for the project would be required to develop a detailed cost plan. Finally, manufacturers were again consulted, such that specific equipment for the gunsmoke generation system could be specified as an example of that which might be used in such a facility.

In summary, the findings of Volume 1, based on an up-to-date review of the literature and discussions with experts, established the scientific guidance for the gunsmoke facility. Specific discussions with in-house and outside experts and manufacturers helped to determine both the feasibility of various candidate approaches and the criteria for the recommended approach. Finally, we relied on existing staff, which has considerable experience in the generation of controlled atmospheres of test aerosols and design of systems for the inhalation exposure of animals to smoke clouds, to design the generation system, assemble and prioritize the criteria, and compile the report.

2. LITERATURE REVIEW OF GENERATION SYSTEMS PREVIOUSLY TRIED WHICH INVOLVE FIRING OF MUNITIONS

2.1 INTRODUCTION

A number of systems have been employed by previous investigators to generate gunsmoke for chemical evaluation studies. The systems can be classed in four categories: closed bombs, gun simulators, small weapons firing actual rounds in test chambers, and field collection of exhaust from the actual firing of real weapons. Many of these systems have been described and reviewed in Volume I. The purpose of the ensuing discussion is to briefly review those systems which were considered for use in a gunsmoke generation facility. The systems are described in more detail in Section 4.

2.2 Closed Bomb Exhaust Generators

Several investigators (Lenchitz, 1965; Lenchitz, 1974; Patrick and Floyd, 1976; Stiefel, 1986) have used closed high pressure bombs to burn small quantities of munition propellants at high pressures for the purposes of generating quantities of gunsmoke suitable for compositional analysis. In most cases, these "bombs" are relatively small, thick walled steel cylinders, whose volume varies from a few hundreds of mL to one or two liters. Usually, a measured quantity of the propellant in question is placed in a small cup, following which the access port of the bomb is closed, usually by screwing on one end of the cylinder. The propellant is ignited by electrodes inside the bomb. During burning, pressures may rise to several tens of thousands of psi. Other investigators (Johnson, et al, 1983) have burned quantities of propellant in large closed chambers (ca 30 - 165 m^3), where pressures essentially remained at ambient levels. Such approaches to the generation of a gunsmoke atmosphere have the inherent advantage of mechanical simplicity. However, it was the conclusion of our assessments in Volume I of this document that, because the time/temperature/pressure relationships under these conditions of burning differ so markedly from those existing during the firing of a real weapon, the chemical composition of the exhaust produced would be considerably different. Seemingly small changes in burning times or conditions can alter the relative composition of exhaust products considerably. Indeed, experiments performed jointly between ORNL and Redstone Arsenal have indicated that increasinging the duration of the burn of a rocket propellant formulation (consisting predominantly of nitrocellulose and nitroglycerine) by a few tens of milliseconds can increase the amount of oxides of nitrogen produced by a factor of ten (Thompson, 1988). Also, the detonation of propellant inside a bomb does not lend itself to straightforward automation.

2.3 Gun Simulators

Gun simulators, such as the Dynagun described by Krier and Black (1974), offer a closer simulation of the firing of a real weapon. In the case of the Dynagun, the detonation of a hand-packed charge produces gases which expand and drive forward a large piston, which eventually travels the length of a cylinder and stops against a metal plate, or anvil. Clearly, the time/temperature/pressure relationships inside the Dynagun are much closer to those produced in an actual weapon. However, the firing rate of such a device is on the order of 3 - 4 per hour, and manual loading is required (Stiefel, 1986). While such a rate might be suitable for chemical composition studies, it would be inadequate for animal inhalation exposure. Goshgarian (1969, 1976) and Farr and Goshgarian (1976) describe the use of so-called micromotors, in which propellant is packed into a closed space, but with an opening to atmospheric pressure at one end of a tube. The configuration is similar to that of a rocket motor. In this device, the time/temperature/pressure (TTP) relationships are closer to those of a weapon firing than those of a closed bomb. However, the systems must be handled manually, and other simulators can probably produce a more realistic gunsmoke atmosphere.

One such simulator is the vented test fixture (VTF), in which a cartridge with the projectile removed is inserted into a test system and fired. The VTF has been used for chemical characterization studies of the exhaust products from the M-16 propellant (Snelson et al, 1983). Agreement between major constituents produced under actual firing conditions and those produced with the use of the VTF was good. For such components as NO, ammonia, and the light hydrocarbon vapors, agreement was poor.

2.4 Field Sampling and Analysis

A number of investigators (Snelson, et al, 1983; Ase, et al, 1985; Lee,. 1982; Kronoveter, 1983; Gill and Madill, 1981; USAEHA, 1984; Hody and Shane, 1966; Hody, 1969, Schumaker and Pollard, 1977; and Yamazaki, 1974) have collected gunsmoke under field settings and returned samples to the laboratory for analysis. Such studies have ranged from collections at indoor firing ranges, to the insides of vehicles and aircraft from which guns were being fired, to the collection of exhausts from the firing of large weapons during military exercises. The greatest advantage of such an approach is that the exhaust to which troops are exposed is actually sampled. Such field validation is likely to be an important aspect of any concerted study of gunsmoke composition. However, many of the toxic products of weapons firing (oxides of nitrogen, hydrogen cyanide, ammonia) are highly reactive, and unless determined in real time by on-line analyzer systems, are unlikely to be present at their original concentrations in any samples returned to the laboratory for analysis. Also, compositions of various exhausts will be affected by atmospheric conditions at the sampling site, and thus make comparison among various formulations difficult at best. In addition, field collections of samples are inappropriate for toxicological evaluation studies of live animals.

2.5 Small Arms Firing Within Enclosures

The most practical approach for the detailed laboratory evaluation of gunsmoke composition appears to be the firing of small weapons in some sort of a small test enclosure inside a laboratory. This approach has been adopted by several investigators (Snelson, et al, 1983; Ase, et al, 1985; Scharf, 1967, Stiefel and Hody, 1970; Rocchio and May, 1973; Wohlford and Sheets, 1971). Probably due to the size of the spent round, the largest reported weapon used in any of these studies was a 50 calibre automatic gun. Herud (1986) has also fired a 50 calibre machine gun housed in a small enclosure, but with the muzzle outside the enclosure, on an open air range, in order to determine carbon monoxide levels from breech exhaust. In general, this sort of an approach, offers a number of advantages for laboratory-based studies. The exhaust, either breech, muzzle, or a combination of the two, is generated in exactly the same manner as it would be under normal use. More sophisticated sampling and monitoring equipment can be used than would typically be available for field use. Noise, and safe disposal of the spent projectile appear to be the greatest difficulties to overcome for a routinely used gunsmoke exhaust characterization facility. These considerations become very important as the size of the munition being tested increases.

We found no evidence in the literature of firing large scale guns (eg. >70 mm) inside enclosures for the sole purpose of exhaust characterization studies. There was also no evidence that any investigators had attempted to scale down large munition propellants to be fitted into small calibre (eg. 7.62 mm) ammunition. This is likely to be due to the physical and burning characteristics of propellants used in larger munitions. The grain size is too large to fit directly into a small round, and it would require a major development effort to scale down the propellant grains to fit into a small round and still burn with the same characteristics as they would in the larger rounds (Hanchak, 1987). However, a reading of the literature and discussions with knowledgeable personnel suggest that it would not be a particularly complex task to use large round propellant grains in 20 mm or 30 mm rounds, with the projectile appropriately scaled so as to produce an exhaust similar to that generated by the firing of large weapons.

3. DESIGN OBJECTIVES, CRITERIA, AND LIMITATIONS

3.1 INTRODUCTION

An effective description of the criteria for a gunsmoke generation/characterization facility must include a statement of the design objectives for the criteria, as well as some rationale for those objectives. The design objective is to describe a facility which is as uncomplicated and inexpensive as is achievable while providing the required well-defined, controlled atmosphere of gun exhaust, produced from a wide variety of munition propellants, and also providing an adequate margin of operator safety. The following is a summary of the desireable features for such a facility, as well as a description of the major constraints likely to exist. The features seem most easily categorized into two groups: those associated with the generation and physical/chemical characterization system, and those associated with the toxicological characterization aspects. Important constraints are described following the discussion of the criteria.

3.2 CRITERIA FOR THE GUNSMOKE GENERATION PHYSICAL/CHEMICAL CHARACTERIZATION FACILITY

3.2.1 Number of Generation Systems

The gunsmoke generation/characterization should contain two generator systems. One system would be dedicated to producing exhaust from small arms firings, for guns between M-16 calibre and a 50 calibre machine gun. Most of the smaller rifles use single based propellants, and the ability to interchange guns within the generator system would facilitate testing and evaluation of a number of propellant formulations while using off-the-shelf ammunition. The second system would employ a larger gun, either a 20 mm or 30 mm size. The gun would fire custom manufactured ammunition, containing the same propellant formulations as exist in munitions for weapons up to 105 mm size. However, the custom manufactured munitions would be scaled (grain size and projectile mass) so that the burning rates, temperatures, and pressures would mimic those achieved in the larger weapons. This larger gun generator would permit the testing and evaluation of a wide variety of double and triple based propellants (as well as any single base formulations if appropriate), normally used in larger sized guns. The two generator systems would permit the evaluation of the range of propellant exhausts to which troops are exposed, without having to construct a single system which could incorporate both large and small guns. The amount of exhaust produced by the firing of a 30 mm shell requires a much larger collection and distribution system than that for an M-16 rifle. It was deemed easier and much less costly to construct one small and one larger system, rather than to develop a single but much more mechanically complex system which could handle both small and large volumes of exhaust.

3.2.2 Collection and Distribution Systems

The exhaust collection and distribution system (CDS) which surrounds each of the two guns should be as mechanically and electrically simple as possible. However, it should be capable of handling either breech-only, muzzle-only, or the combination of muzzle and breech exhaust. This capability was incorporated after receiving guidance from project management at USABRDL that both types of exhaust are relevant to field exposures of troops in both training and combat scenarios. Since many of the compounds in the exhaust are reactive, it is possible that the relative composition of the exhaust will change as it stands with time (aging), thus altering its potential toxicity. The collection and distribution system should be designed in such a manner that it permits characterization of both aged and unaged exhaust in a controllable fashion.

In order to minimize the number of relatively expensive custom ammunition rounds which need to be fired to produce a given concentration atmosphere in a specified length of time, the system should be as efficient as practical. The system need not be completely quantitative in its collection of exhaust products. However, the fraction of materials collected should be amenable to accurate determination. Also, there should be minimal fractionation of the exhaust by the system. In other words, the relative concentrations of particles of all sizes and of vapors should be constant throughout all parts of the system.

3.2.3 Operator Intervention

The generator should be able to function essentially automatically, with minimal jgoperator intervention. This minimizes the cost of operation. However, the firing and distribution system should incorporate the ability to be run either by time-programmed commands, or by a driver monitoring the concentrations of the exhaust constituents. For animal inhalation exposure, it seems most desireable to maintain a constant concentration exposure atmosphere. However, the act of firing is a discrete event, so that changing dilution air ratios as exhaust is removed from the collection system is required to maintain a constant concentration atmosphere. This is most easily achieved by placing a monitoring device (eg. for carbon monoxide) into a feedback circuit. However, such systems have a finite response time, and in order to prevent unnecessary excursions in constituent concentrations, it may be prudent to provide for time programmed overrides of the monitor driven feedback circuitry. Of course, the system should be programmable for intermittent expsoure of animals as well as continuous exposure.

The generation/collection/distribution system should be accessible for complete cleaning on a daily basis. However, it should be designed to operate without breakdown for periods of up to six hours. Six hours is a common time period for "all day" inhalation exposures to toxic substances (Lock, et al, 1984).

3.2.4 Safety Considerations

The system should be as enclosed as possible, so that personnel working in the area can not be exposed to an errant round. The collection/distribution system should have a safety interlock on the firing command circuit, to ensure that any valves which must be fired through are open prior to firing. Also, noise should be minimized so that the personnel working in the area should not have to wear special hearing protection.

3.2.5 Engineering Flexibility

The overall facility ideally should be constructed in a modular fashion. That is, the generation/characterization areas should not have to be integrated into the toxicological facilities if that is not required. For example, the system should be designed such that exposure atmosphere samples destined for chemical studies can be collected in ducts leading to the animal exposure chambers, rather than from the chambers themselves. The animal exposure facility will be expensive to construct, and chemical characterization efforts are likely to precede the biological studies. The generation area might serve as a central core around which the biological facilities would be constructed.

3.3 CRITERIA FOR THE TOXICOLOGICAL CHARACTERIZATION FACILITY

As stated in the introduction to this volume, the problem definition study will not describe those aspects of toxicological facilities which are generic to such operations, but rather focus only on those aspects of the facilities which will be relatively specific to gunsmoke characterization.

3.3.1 Toxicologic Evaluation Flexibility

The toxicologic characterization facility should be capable of housing a number of types of biological studies. Inhalation studies are the most likely to be performed. Capabilities should be maintained for both nose-only and whole body exposures. In the case of the firing of small weapons, the volumes of exhaust may not be adequate to perform whole body exposures. Conversely, many inhalation studies are performed on rodents. Given that these animals preen considerably, they are likely to receive a relatively large oral dose of any gunsmoke-related particulate matter if whole body exposures are performed. Because of the differences of opinion within the toxicological community, if the operation is to be designed as a user facility, provisions for both nose-only and whole body inhalation exposures should be made.

If in vitro studies are to be performed, then separate chambers or flow cells should be constructed for exposure of test plates, etc.to exhaust gases and particulates. For any studies where condensed products are required (such as skin painting carcinogenicity), provision for condensed exhaust product collection must be made. Such may require the long-term, rapid firing of one of the generating guns, which in turn may necessitate the use of water cooled barrels. It is likely that some sort of cryogenic trapping will be needed to collect the exhaust products.

3.3.2 Live Animal Considerations

In any study in which live animals are employed, the animals represent a considerable monetary investment, especially after they have received a number of exposures. Thus, the assurance that the animals do not perish as a result of a system failure is critical. If the dilution air should stop flowing, depending on the concentration of gunsmoke in the exposure atmosphere, that atmosphere may be depleted in oxygen or at too high a temperature or concentration of a toxic constituent. Thus, failsafe monitoring of the exposure atmosphere is recommended, perhaps through the use of a thermocouple and an oxygen monitor. Also, in order to prevent them from overheating during long duration exposures, specialized containment for rodents undergoing nose-only exposure may be required. For animals larger than rodents or small birds, the quantity of exhaust atmosphere which can be produced is likely to limit inhalation exposures to respiratory tract-only. In addition, live animals must be insulated from the noise of the weapons firing.

3.4 FACILITY LIMITATIONS

The nature of the material being studied and the manner in which it must be produced is likely to place some constraints on the generation/exposure facility. Such limitations are discussed briefly below. Solutions to the issues raised are described in Section 5 below.

3.4.1 Limiting Toxic Constituents

An assessment of the composition of gunsmoke as described in Volume I of this document indicates that the most prevalent toxic constituent in the exhaust is likely to be carbon monoxide (CO). Its presence will likely control the amount of exhaust which must be generated to perform any exposures, as well as the magnitude and duration of the exposures. Because of the acute toxicity of CO at relatively high concentrations, it seems unlikely that inhalation or other bioassays would be performed at CO levels exceeding 1000 ppm. Thus, we anticipate scaling the generation apparatus to deliver a maximum CO concentration of 2000 ppm to the exposure atmosphere. It is likely that most of the exposure atmospheres will be considerably less concentrated than this. It also seems likely that the amount of gases produced by small weapons will constrain the types of bioassays which can be performed. For example, determination of the acute inhalation toxicity of the breech exhaust from an M-16 rifle will be limited to nose only exposure of rodents because of the small quantities of exhaust which can be produced, even with repeated firings.

3.4.2 Firing Noise

There is considerable noise associated with the firing of a large gun. Not only must humans working in the area be shielded or wear hearing protection, but animals undergoing inhalation exposure or those housed near the test facility must be protected. Certain animal species are particularly susceptible to this form of stress. The amount of noise produced may constrain the relative proximity of the generation and biology modules within the overall facility.

3.4.3 Firing Rate Limitations

An unwanted byproduct of the detonation of any munition propellant is heat. Rapid firing of any weapon may cause the gun barrel to overheat. Also, the gases produced by the firing are hot, and likely to transfer that heat to the collection/distribution system. While an engineering analysis of the required firing rate for the larger gunsmoke generator indicates that the firing rate should not be sufficient to cause heat build-up in the gun barrel (see below), the need to maintain the small gun barrel at an acceptable temperature may place a constraint on the allowable firing rate in cases where larger quantities of exhaust must be produced.

3.4.4 Spent Projectile Handling

If the recommended approach of using two gun sub-systems to generate the gunsmoke exhaust is used, as opposed to a closed bomb or a gun simulator, the issue of what to do with the spent projectile (which in this application becomes useless as soon as it exits the muzzle) must be addressed. For the small calibre weapons, this appears to be a relatively straightforward problem, as a number of commercial bullet catchers are available. As the calibre of the round fired increases, the energy which must be dissipated to trap the projectile increases dramatically. Commercial bullet catchers for 20 or 30 mm projectiles do not exist. While custom made bullet catchers for large rounds are very effective (Hanchak, 1987), they have usually been designed for limited firing. The trapping must be performed in such a manner so as to not endanger those working in the area.

3.4.5 Acquisition of Down-sized Ammunition

For the larger gun generator to be effective, it must be able to simulate the exhaust produced when a much larger weapon is fired. To develop a 20 mm round which, because of the ratio of its projectile mass to the burn time, generated pressure, and barrel length, as well as the propellant composition, will produce an exhaust which is compositionally similar to that produced when a 105 mm or 150 mm round is fired may be the most difficult development aspect of this project. However, such an effort would likely be fruitful (Daniel, 1987). The availability of the ammunition at a reasonable price is likely to control the minimum size of the larger weapon. For example, from an engineering design and bullet catching standpoint, the smaller the weapon used to generate the exhaust, the less expensive the facility. However, the cost of re-engineering the triple base propellant used in a 105 mm shell and an appropriate projectile so that both fit in an M-16 round and still produce exhaust compositionally similar to that produced by the firing of the 105 mm shell would be prohibitive. For a 20 mm or 30 mm shell, the goal seems attainable.

3.4.6 Safeguards and Security Issues

Guns and ammunition are perceived to be dangerous items by many individuals. Proper storage of each, both from a safety and a security standpoint, is imperative. Fire, impact, or electrical detonation of stored ammunition represent significant safety concerns. The siting of such a facility at certain government installations may be considered inappropriate. For example, the presence of both an automatic rifle and ammunition in or near a facility where chemical agents or strategic nuclear materials are present may be perceived to require more intensive security provisions than those which would be necessary in a facility which does not have these materials.

3.4.7 Specialized Staffing Requirements

The location of a gunsmoke generation/characterization/exposure facility is likely to be limited to a larger institution where specialized staff representing a variety of disciplines are available on both a routine and emergency basis. Operation of the facility would require individuals either skilled or specifically trained in both large and small gun operation, as well as staff representing both the physical and biological sciences. A more thorough description of the professional staff required to operate such a facility is provided in Section 5.12.

4. EVALUATION AND COMPARISON OF ALTERNATIVE APPROACHES

4.1 INTRODUCTION

There are a number of scientifically justifiable approaches to the design of a facility to generate and characterize gunsmoke exhaust. The approaches vary in their degree of similarity to actual gun exhaust -- from actual gun firing to mixing toxic gases in varying ratios for animal exposure. Each was considered in the course of this problem definition study. The final recommendations of this report are the product of the assessment of the multiple strengths and weaknesses of each approach. In the following sections, each considered approach is described briefly from a conceptual standpoint, its advantages and disadvantages are discussed, and an overall assessment as to its feasibility and cost is made. Costs given below are rough estimates based on experiences with fabrication of instrumentation and control systems at Oak Ridge National Laboratory, and are believed to be similar for most institutions where such a facility would be located. Cost estimates are for fabrication only, and do not include design costs, unless stated otherwise, which are expected to be 10 - 20% of fabrication costs. No estimates of the resources required for construction of the biological testing facilities are given, since costs are expected to be essentially the same for all options, and therefore would not impact on the choice of which exhaust generation option to pursue.

4.2 FIRING OF ACTUAL WEAPONS

4.2.1 Description

In this alternative, actual weapons are used to fire military munitions. Muzzle and breech gases would be collected separately by firing through a cylindrical chamber with open valves at each end. Immediately following the discharge of the projectile from the system, the valves are closed and the exhaust products diluted and distributed. Such a system for small weapons would be conceptually similar to those reported as having been developed by other investigators (Snelson, et al, 1983; Ase, et al, 1985; Scharf, 1967, Stiefel and Hody, 1970; Rocchio and May, 1973; Wohlford and Sheets, 1971). To our knowledge, the nearest thing to such a system which has been reported for large weapons has been field sampling of the exhausts produced by large guns. However, given enough resources, a laboratory system for the firing of full scale guns could be developed. Conversely, an approach similar to that adopted by Herud (1986), in which the weapon is placed on a firing range, enclosed, and the exhaust products collected, might be adopted. Chemical characterization and inhalation exposure facilities would have to be constructed on the range, or in the case of live animal exposures, the animals could be brought to the generation site on a daily basis, in a large vehicle or semi-trailer, previously equipped with exposure chambers.

4.2.2 Advantages of Approach

1. The gun sub-system of the generator, and the ammunition itself would be off-the-shelf technology. No development would be required, and its performance during repeated use over long periods of time is well documented.

2. The chemical composition of the exhaust products would be identical to that to which troops are exposed, since the actual weapons are those which are used to generate the exhaust.

3. Spent projectile containment for the small weapons could be achieved with commercially available technology.

4.2.3 Disadvantages of Approach

1. Both large and small gun sub-systems would require the development of a breech/muzzle exhaust collection and distribution system (CDS).

2. The CDS for the large gun or guns would be very large, and would likely require a substantial effort to engineer the system to withstand the heat and pressure associated with the muzzle blast of a large gun.

3. For the larger guns, containment of a spent projectile would require a considerable effort. An alternative to containment would be to site the generation system on an existing firing range at a military base. However, this would likely require a new structure to be constructed to house the gun and CDS. Also, location of the facility at such an installation would limit the number and type of scientific staff available to work on the chemical and biological characterization studies.

4. Auto loading and firing systems for many of the larger guns are not available. Thus, manual loading would be required. Alternatively, an auto loading system would have to be developed.

5. For the large gun-based system, noise generated would be considerable, and would necessitate a substantial degree of noise abatement and/or insulation efforts.

4.2.4 Cost

Exact costs for such a facility would require definition of the various siting options. For small weapon (up to 50 calibre) exhaust production, costs for the gun sub-system, collection and distribution system and bullet catcher would range between $250,000 and $350,000. For the large gun based system situated on an existing firing range in such a manner that no costs would be associated with stopping the spent projectile, the CDS would likely cost something more than $2,000,000. The latter does not include development costs associated with an auto loading system. If the generation system and the CDS were located inside an existing lab, the technology required to capture the spent projectile from a large gun on a routine basis would likely increase the costs to more than $5,000,000.

4.2.5 Feasibility

As described above, the small gun or rifle based generation system is very feasible and in fact is one of the preferred options. The large gun based system, while technologically feasible, seems unlikely to be practical. Placing the gun out on a firing range to allow the spent projectiles to fall to the ground is more practical than locating such a system inside an existing laboratory. However, such would still require a dedicated analytical and biological support facility, which would increase the overall cost proportionately.

4.3 FIRING OF DOWNSIZED GUNS USING SCALED DOWN AMMUNITION

4.3.1 Description

This option could almost be considered a variation of that described above, in that it entails the firing of a weapon using a munition which produces a projectile. The major difference between the two options involves the use of a "gun" and ammunition specifically developed for the evaluation studies described here. In this case, the two would be designed to use the same propellants as those used in larger guns. The projectile, either a conventional steel ball or a sabot loaded with steel or lead shot, would be scaled such that the TTP relationships which exist in the large guns would be maintained by the "scale model gun." It would be necessary to also scale the length of the barrel, so as to mimic more effectively the TTP relationships. The overall objective in reducing the size of the gun from, for example, a 105 mm to a 20 mm weapon would be that the system could be situated within an existing laboratory, capturing the spent projectile would utilize existing technology, and except for a modest scale-up in size, the CDS would be identical to that developed for the smaller gun system (up to 50 calibre) described above.

4.3.2 Advantages of Approach

1. With the exception of the changed barrel length, the technology of a "scaled down" gun is similar to that which exists for actual weapons. For the most part, existing gun components, such as the auto loading systems and the breech, could be used.

2. Stopping projectiles from 20 mm or 30 mm weapons within a laboratory environment is proven technology , and can be accomplished in a relatively straightforward manner.

3. Given an appropriate development effort, the scaled down munitions should produce an exhaust identical to that of the larger real world artillery. It is likely that grain shape and structure can be easily maintained, and that only the grain length must be reduced to fit in a 20 mm cartridge.

4. The scaled down gun and associated system can be situated within an existing laboratory. This makes combining the overall system with the scientific staff (chemical and toxicological) required to characterize the exhaust a much more feasible undertaking.

5. The CDS for the scaled down gun should be sufficiently small for near quantitative recovery of the muzzle and breech exhaust.

4.3.3 Disadvantages of Approach

1. The most technologically difficult aspect of this project will be the development of the custom ammunition. This would likely be handled as a sub-contract to the Army Armament Development Command at Picatinny Arsenal, and eventually manufactured at a munitions facility, such as that at Radford, Virginia.

2. An engineering assessment would have to be performed to verify that existing loading and breech assemblies in 20 or 30 mm weapons could withstand any differences in pressure existing as a result of the firing of the non-conventional munitions.

3. The scaled down gun would require the development of a breech/muzzle exhaust collection and distribution system (CDS). However, the system for the 30 mm gun would not be expected to be significantly different from that for the smaller gun systems. Thus, it would only represent a small increase in development costs.

4. Some design work would be required to provide a range of appropriate barrel lengths for a number of different scaled-down munitions.

5. Trapping of the spent projectiles must be accomplished with a system which is not commercially available, but must be custom designed and constructed.

6. Noise will still be considerable with the scaled down system.

4.3.4 Costs

Costs for the scaled down generation/characterization facility are dependent on whether a CDS has been previously built and tested for the small gun exhausts. If such is the case, then costs for the larger, but scaled-down gun CDS may run as little as $180,000. If a new gun subsystem were to be developed specifically for this project, the design study for the scaled down gun would likely be performed under sub-contract to an appropriate expert institution, and would cost between $50,000 and $100,000 (Hanchak, 1987). The scaled down gun itself would probably cost about $100,000 to manufacture. Alternatively, an "off-the shelf" 30 mm cannon could be purchased and modified for less than $50,000. Development of the custom grade ammunition would likely cost about $100,000 for development of three types of rounds.

4.3.5 Feasibility

The approach appears to be highly feasible. Assuming the successful development of custom formulation munitions to mimic the performance of larger rounds, all of the remaining technological hurdles appear low. Gun systems of 20 mm to 30 mm size are routinely fired inside laboratories, and the spent projectiles are stopped with steel plate and railroad ties. The exhaust CDS would be conceptually quite similar to that use for the guns 50 calibre or smaller. All of the control systems would be identical; probably the greatest difference would be the size of the exhaust gas containment chamber (see below) and the diameter of the valving systems.

4.4 FIRING OF GUN SIMULATORS

4.4.1 Description

Gun simulators have been used to more closely mimic the pressure-time performance of propellants being fired in large guns without the bother of having to deal with a projectile. The Dynagun, one of the most widely cited gun simulators, has been described in detail elsewhere (Adams and Krier, 1975; Krier, et al, 1975; Krier and Black, 1974). Briefly, the Dynagun ballistic simulator is scaled to simulate a 155 mm firing system. Essentially, the propellant charge is ignited, which drives a piston down a tube, where it is stopped. The propellant charge/chamber volume ratio is scaled and the propellant gases are vented in such a manner that the pressure - time curve for the Dynagun is similar to that generated in the actual firing of a 155 mm gun. The Dynagun, which is operated manually, can be fired at a rate of once every 10 minutes (Domen, 1988). The maximum propellant load of the system currently in use is about 95 g. A larger system is under development, which will be capable of handling a 1 pound charge.

4.4.2 Advantages of Approach

1. No projectile is fired by the gun simulator. Thus, a somewhat smaller laboratory is required to house system, and there are fewer safety concerns involving containment of spent rounds.

2. The Dynagun can be designed to yield proper TTP relationships for a variety of munition loads.

3. If the breech assembly of the Dynagun were properly redesigned, off-the-shelf blank rounds could be used, reducing costs of ammunition considerably.

4. Potentially larger quantities of exhaust could be produced by the larger Dynagun.

4.4.3 Disadvantages of Approach

1. The piston/cylinder/anvil stop arrangement is an integral part of each Dynagun, and represents a unique mass and inertia against which the propellant gases must expand. Redesign of the current Dynagun configuration would be required for each propellant formulation used, in order to maintain the appropriate TTP relationships. Thus, several different gun simulators would be required to test a variety of propellant formulations.

2. Current operation of the Dynagun is manual. Considerable design effort would have to be expended in order to produce an autoloading and firing mechanism.

3. The current system is not designed for frequent and repeated use. Such would clearly cause considerable wear and tear on the piston/anvil arrangement. Redesign of this portion of the system and replacement with stronger materials would be required.

4. Noise would be comparable to other gun systems, and would necessitate sound proofing the animal exposure chambers as well as the chemical characterization facility.

5. A CDS would have to be designed for the Dynagun. Although somewhat different, it would probably be reasonably comparable to that used for the small gun system, so it would not require design from the ground up.

6. The gun simulator would not produce metal or metal oxide particulates associated with erosion of the gun barrel or projectile.

4.4.4 Costs

The existing Dynagun is estimated to cost $30,000 to duplicate (Doman, 1986). However, to develop an autoloading and firing mechanism is estimated to cost approximately $250,000 (Domen, 1986). Redesign of the piston and anvil assembly are likely to cost about $100,000. The CDS costs are expected to be comparable to those for the scaled down gun CDS, as described above.

4.4.5 Feasibility

The gun simulator appears to be a more technologically difficult approach to pursue than that of the 30 mm gun firing downsized ammunition. Essentially, the Dynagun was designed for occasional testing of limited quantities of munitions propellants, and is operated manually. To test different propellant formulations, different firing chamber volumes, piston and anvil assemblies must be employed. Costs associated with design and construction of a number of different gun simulators to test different propellant formulations would be considerably greater than those associated with the 30 mm gun option, all to gain the chief advantage of not firing a projectile. And costs associated with trapping the spent projectile from a 30 mm round are not expected to be high. We conclude that the gun simulator approach is feasible, but is not recommended.

4.5 CLOSED BOMB FOR GENERATING SIMULATED GUNSMOKE EXHAUST

4.5.1 Description

The closed bomb has been used by a number of investigators to evaluate the pressure generated by various propellant formulations, and has been described in detail elsewhere (Domen, 1976). Closed bombs consist of thick walled steel cylinders of volumes ranging from 200 mL to 2.4 L which can be closed at one end by screwing in a steel cap. Small quantities of propellants, usually 0.2 g/mL of bomb capacity are placed inside and the end of the bomb is sealed. Using a system by which guncotton is wrapped with Nichrome wire attached to the breech electrodes, which in turn contacts clean burning ignitor, ultimately the propellant is ignited. Typically, the pressure rises rapidly as the propellant burns to a maximum, and may drop slightly as the gases produced begin to cool. Typically, closed bomb systems are operated manually.

4.5.2 Advantages of Approach

1. The bomb is mechanically simple. It has no moving parts and is simple to operate.

2. The charge used is relatively small and can be easily scaled so that the desired pressure maxima are achieved.

3. Propellant formulation changes can be made relatively easily, merely by changing the material added to the bomb.

4. A high speed projectile is not normally released from the system. (But see Disadvantage No. 6 below.)

4.5.3 Disadvantages

1. The chemical composition of the exhaust may differ considerably from that produced from the same propellant fired from a real gun, because the TTP relationships are completely different from those which exist in a real gun.

2. Most closed bombs have fairly small volumes. Considerable scaling up would be required in order to burn sufficient quantity of propellant to produce enough exhaust to expose a number of animals simultaneously. This might decrease any degree of inherent safety in the system.

3. Extensive redesign of the closed bomb would be required to automate its operation. A complex, ultra-high pressure valve system to release the exhaust would have to be developed.

4. Since all the propellant is burned under the same conditions, there would be no difference between "breech" and "muzzle" exhaust.

5. A CDS would have to be designed and constructed which would be considerably different from that used with the small gun based system.

6. Blowing out of the igniting electrodes from the ends or sides of the bombs is an occasional phenomenon. Judging from the size of the craters in the reinforced concrete walls of the rooms in which the bombs are located, the force with which the electrodes are ejected is considerable. Special shielding would be required in order to protect people and property from damage during all firings of the closed bombs.

4.5.4 Costs

The closed bomb itself is fairly inexpensive to manufacture, perhaps a few thousand dollars. Little effort was made to estimate the costs to automate such a system, primarily due to the inadequacy of the closed bomb to generate a material with a composition sufficiently close to that of gunsmoke.

4.5.5 Feasibility

The approach of using a closed bomb to generate gun exhaust for both chemical and toxicological characterization is very limited in its utility. The bomb would have to be redesigned extensively, such that it could operate on an automated or semi-automated basis. And as stated previously, the material generated by the system would not be sufficiently similar in composition to actual gunsmoke to justify such a large effort.

4.6 SMALL WEAPON EXHAUST PLUS ADDED TOXIC GASES TO SIMULATE A LARGE WEAPON

4.6.1 Description

This approach is derived from that described in Section 4.2. In such an approach, a small gun would be mounted in a test facility, similar to that described above. Exhaust components would be generated by firing the small weapon, and would be a primary (but not the <u>only</u>) source of vapor phase materials for characterization, and the primary source of particulate phase materials. Other metal containing particulates may have to be added to simulate those normally originating in primers, etc. In order to simulate the composition of the large weapon exhaust, the small gun exhaust would be supplemented with a known volume of a standard gas mixture. This would be introduced immediately following the firing of the actual weapon. The gas mixture would be composed so as to compensate for any differences between the vapor phase composition of the small weapon and that of the large weapon. Likely constituents of the added gas mixture would include carbon monoxide, carbon dioxide, nitric oxide, hydrogen cyanide, ammonia, methane, and some selected low molecular weight organics. Because of the cross reactivity of some of the compounds (such as the organics with the nitrogen oxides), it would not be prudent to prepare standard gas mixtures of the species. Rather, a series of individual cylinders containing either singular species or non-reactive gas mixtures (such as CO and CO_2) would be used to feed the collection/distribution system. Such an approach would require extensive field measurements to determine the composition of the large gun exhaust, plus detailed measurement of the small gun exhaust composition, in order to determine the exact amount of make-up gases to add.

4.6.2 Advantages of Approach

1. This approach eliminates the need for the firing of a larger weapon, disposing of the spent projectile, or providing the development costs associated with the downsized ammunition, as described in the second option above.

2. Once the gas distribution system were developed, operating costs would be relatively low. Even if several cylinders were required simultaneously, each could last as long as a week under normal operation.

3. The gas injection/mixing system would be straightforward to construct, as it would consist of a number of solenoid valves controlled by a programmer between the gas cylinders and a small mixing manifold.

4.6.3 Disadvantages of the Approach

1. Considerable effort would be required to characterize real gun exhaust under field conditions, in order to provide a data base for producing a mixture of make-up gas with an appropriate composition. Essentially, the facility to be developed would be limited to toxicological characterization. That is because all of the chemical characterization studies would have been already performed in the field.

2. It would be essentially impossible to provide for all or even most of the trace gases present in the vapor phase of the large gun exhaust in a well defined gas mixture. Also, the relative amounts of the trace gases would likely change as the simulated propellant was changed. This would necessitate having a number of gas mixtures prepared. Essentially, this effort would amount to a partial simulation of the exhaust gases.

3. It is difficult to imagine how the particulates generated by the large gun could be simulated. Perhaps a somewhat suitable substitute might involve a separate generation of small gun exhaust, collection of the particulates from that firing, and redispersal of the particles into the collection and distribution system during the large gun simulation. However, these would not have the same composition as the particles generated by large guns, especially when the latter would be generated from the firing of a propellant of markedly different formulation.

4.6.4 Costs

The gas distribution and mixing hardware required to add to the existing small gun facility to simulate the larger gun would likely be relatively inexpensive. Total costs, including parts, labor, and check out would be less than $100,000. However, the costs of an extensive field based sampling and analysis study of the composition of the exhaust of the larger guns would be more than $1,000,000.

4.6.5 Feasibility

The proposed approach is definitely feasible. It relies entirely on existing or near-existing technology. However, it will not produce a material which is as similar compositionally to large gun exhaust as that which could be achieved by other options. Thus, while the approach is feasible, it is not recommended.

4.7 SIMULATION OF LARGE AND SMALL GUN EXHAUST USING AN AEROSOL OF MIXED GASES AND PARTICULATES

4.7.1 Description

Depending on the extent of accuracy of the simulation desired, such an approach could be relatively simple or exceedingly complex. On the simple end of the spectrum, a gas distribution and mixing system similar to that described above could be combined with a solids aerosol generator producing a cloud of metallic dust or inorganic compounds related to those produced by actual gun firing. Biphasic exposure atmospheres simulating military obscurants have been generated for both chemical characterization and inhalation exposure studies (Moneyhun, et al, 1988). On the other end of the spectrum of complexity might be a system which includes a gas mixing system with a very large number of cylinders feeding it, a small generator to combust continuously small quantities of propellant at atmospheric pressure, to provide for a small amount of trace gases which could not easily be provided from a cylinder, plus resuspended particulates collected from field firings of both small and large weapons.

4.7.2 Advantages of Approach

1. No projectile would be produced, nor would noise or safety considerations be significant factors.

2. The simple version of the system would be relatively inexpensive to develop and construct.

4.7.3 Disadvantages of the Approach

1. An extensive field program to chemically characterize the exhaust from large and small guns would have to be undertaken, so that a data base would exist for comparing the real with the simulated exhaust. One has to know what one is simulating before successfully simulating it.

2. The degree of simulation possible, even with a relatively complex system, would be much less than that achievable with a relatively simple small gun exhaust collection and distribution system.

4.7.4 Costs

Costs for the development and fabrication of a simple gas mixing and distribution system coupled with a solids generator would be approximately $200,000. The cost for a complex system could approach $1,000,000. This does not include the costs required for a detailed field study of the composition of the actual gun system exhausts.

4.7.5 Feasibility

The small system would be simple to envision and would probably function well after only a minimal development effort. Since the complex system could be comprised of a number of subsystems, it is difficult to determine its feasibility. However, as with the option described immediately above, it will not produce a material which is as similar compositionally to any gun exhaust as that which could be achieved by other options. Thus, while this approach is feasible, it is not recommended.

4.8 SUMMARY AND RECOMMENDATIONS

Essentially, six options have been reviewed. Each has its advantages and disadvantages. The firing of real or downsized guns offers the considerable advantages of a realistic exposure atmosphere to characterize chemically and toxicologically. However, this approach has the disadvantages of noise and a requirement to stop a high energy projectile. A gun simulator has the advantage of a "contained" projectile. However, simulators in existence, such as the Dynagun, have been designed for occasional firings, and not repeated use, as would be the case in an inhalation exposure situation. Closed bombs also offer the advantage of no projectile. However, because the temperature and pressure functionality is so different from that of an actual firing of a gun, the degree to which such a system can accurately simulate a real gun is questionable. And the approach in which mixtures of major and minor constituents are used does not appear to sufficiently mimic the real exhausts to be worthwhile pursuing.

From discussions with various experts and evaluation of the appropriate literature, it became clear that there are sufficient differences in the propellant formulations to require that many different types be tested. It was determined that constructing a facility to handle large weapons firing real projectiles on a frequent basis would be very expensive and would limit siting options to military bases, where it would likely to be more difficult to maintain both the specialized support facilities and qualified staff to operate a facility. Thus, a compromise approach was adopted. The facility should be developed in stages. Two gun exhaust systems would be constructed in the gunsmoke facility, one to be based on a relatively small weapon, such as the M-16 rifle or M-60 machine gun. This would represent existing technology, and would act as a template for the development of a somewhat generic exhaust collection and distribution system. It would also be used in characterization studies of single base propellants which could be loaded into small size ammunition with little or no development effort. The second gun would be a larger system, probably a lightweight 30 mm cannon, such as that used on the Apache helicopter, with a modified barrel assembly. This gun would fire custom manufactured rounds produced as a result of a separate development effort. This development project would identify those parameters which are critical to the production of temperature pressure functionality identical to that produced by the firing of large weapons. Essentially, the composition, grain size, primer, and loading would be scaled to a given projectile mass, so that the resulting firing would be a small scale version of that of a much larger gun. Thus, a number of different types of ammunition, representing a variety of real gun/munition combinations, would be produced which would fit into and could be fired safely from the same 30 mm cannon. Then, essentially the same CDS as developed for the small gun could be scaled up to enclose the 30 mm cannon. The details of this proposed approach are described below.

5. RECOMMENDED FACILITY CRITERIA AND FEATURES

5.1 INTRODUCTION AND PURPOSE

A set of objectives for a facility to generate gun exhaust for chemical and toxicological evaluation has been defined. A number of possible approaches to accomplishing this task have been considered, and one has been recommended. The manner in which such a facility would operate is the subject of this section of the report. The overall purpose of the section is to define those criteria and operating parameters which would describe the facility, as well as to raise and suggest solutions to related issues. The focus of this section is more practical than were those of previous sections. However, the design and operation is still conceptual in nature, and the specific details of how such a facility might function would require that the appropriate development studies be undertaken. The operational aspects of the facility, including the exhaust generation, collection/distribution, monitoring, and projectile containment systems are discussed below, as well as the sampling and analytical instrumentation required in the facility. In addition, some comments have been made about the supply of downsized ammunition and technical staffing requirements, and issues have been raised concerning safety and security, as well as toxicologic concerns related to gun exhaust characterization.

5.2 GENERATION SYSTEMS

The systems which produce the gun exhaust are obviously at the heart of any exhaust characterization facility. As stated above, the most practical approach to generating a wide variety of compositionally relevant exhausts is believed to be the use of two gun systems. Both are of a size that permits reasonably normal laboratory operation in both the chemical and toxicologic evaluation studies. One system is used to generate exhausts from the firing of small weapons, while the other uses specially developed scaled down ammunition to mimic the firing of much larger weapons. Essentially, the ammunition is constructed in such a manner that a physical chemical assessment of its functioning indicates that it will produce exhaust essentially identical to that generated by the firing of a larger gun. It is the purpose of the facility to determine the chemical and toxicological properties of that exhaust.

One approach to developing a gunsmoke generator is to develop a new gun from the ground up. However, the approach has several drawbacks. It would be very expensive to develop, would not be identical to the systems currently in use by the military, and would not have historical reliability. In addition, such an approach appears to be unnecessary, as a wide variety of rifles and cannons exist which could be interfaced to the collection/distribution system in a straightforward manner. This general approach has been followed by a number of investigators (Hoke, et al. 1988; Snelson, et al, 1983; Ase, et al, 1985; Scharf, 1967, Stiefel and Hody, 1970; Rocchio and May, 1973; Wohlford and Sheets, 1971) with considerable success for small guns. Since very large projectiles can be fired within laboratories, there appears to be no reason why a larger cannon of the 30 mm size would not be effective for the generation system for the exhausts from double and triple base propellants. The nature of the chosen guns is described briefly below.

5.2.1 Fixed Mount Small Rifle

The weapon chosen to be the primary small arms exhaust generator is an M-60 machine gun, which fires 7.62 mm ammunition. However, it seems most prudent to design the weapon/CDS interface such that small arms could be easily interchanged and tested. It may prove easier to exchange small rifles than to procure special ammunition with a variety of propellants which would fit a single gun. Nevertheless, the M-60 was selected as the initial gun because it fires one of the largest projectiles which can be easily stopped using the commercial bullet catcher described below. It is still sufficiently large that a number of single base propellant formulations, which are frequently used for small rifles, could be packed into the volume of a 7.62 mm cartridge, if this appears to be the most practical approach. Some modification to the ammunition feed system may be required, so that a large number of rounds could be fed through the system. Also, a slight modification may be made to the breech assembly, so that prior to cartridge ejection, the volume of the cartridge would be rinsed out. This modification is discussed in Section 5.3.

5.2.2 30 mm Cannon

The weapon chosen for the generator of the simulated large gun exhaust is the so-called "Light 30," which is the 30 mm cannon used on the Apache helicopter. This cannon was chosen because the 30 mm round which it uses should be large enough to incorporate the priming and ignitor materials and propellants used in the larger gun rounds (up to 155 mm) with only a modest amount of development effort for the downsized ammunition (Hanchak, 1987), without having to deal with the much higher energy projectile fired by the Galway 30 mm cannon used on the A-10 aircraft. The latter round, which is normally packed with 1800 grains of propellant, has 4 times the muzzle energy of the "Light 30" (Trifiletti, 1988). The smaller round is loaded with 800 grains, or ca. 52.5 g of propellant. As with the smaller rifle, some modification would have to be made to the breech block, in order to provide for rinsing out of the spent cartridge. Also, minor modifications would be made to the barrel, such that its connection with the CDS, described below, would be airtight. Other barrel modifications might include changes in length or rifling, or material, such that the time/pressure curves or composition of the exhaust would more closely mimic that of the larger guns.

5.3 EXHAUST COLLECTION AND DISTRIBUTION SYSTEM (CDS)

5.3.1 Introduction

The gun, as an exhaust generator, is probably the simplest part of the overall gunsmoke exhaust characterization and exposure facility. The need to deliver a reasonably constant concentration of diluted exhaust products for inhalation exposure from what is inherently a discrete and intermittent process necessitates the provision of a reasonably sophisticated exhaust collection and distribution system. The purpose of the system described in some detail below is to provide for the expeditious collection of the exhaust products and their dilution and distribution to either instruments and sampling equipment for chemical characterization studies, or for biological testing. The system is portrayed in Figure 1, and operates as follows (assuming both breech and muzzle gases are to be collected and distributed): Once the munition is loaded automatically into a pressurized firing chamber, and the system is determined to be prepared for firing, the round is fired through two valves into a bullet catching device. As the spent casing is prepared for expulsion from the breech, a jet of clean air is exposed which "rinses" out the empty cartridge. After the breech gas is forced down through the barrel and into the main collecting chamber, the collection chamber is sealed off, and the gases are gently (but not necessarily completely) mixed. Next, the exhaust is drawn through the proportioning system and diluted to an appropriate concentration. Sometime during this cycle, a collapsible bag chamber is filled with some of the exhaust products, so that a reservoir will be available to drain in order to maintain a constant concentration of diluted exhaust products during that part of the cycle when the collection chamber must be flushed and prepared for the firing of the next round or series of rounds. During the first part of the next collection cycle, in which the exhaust is being supplied

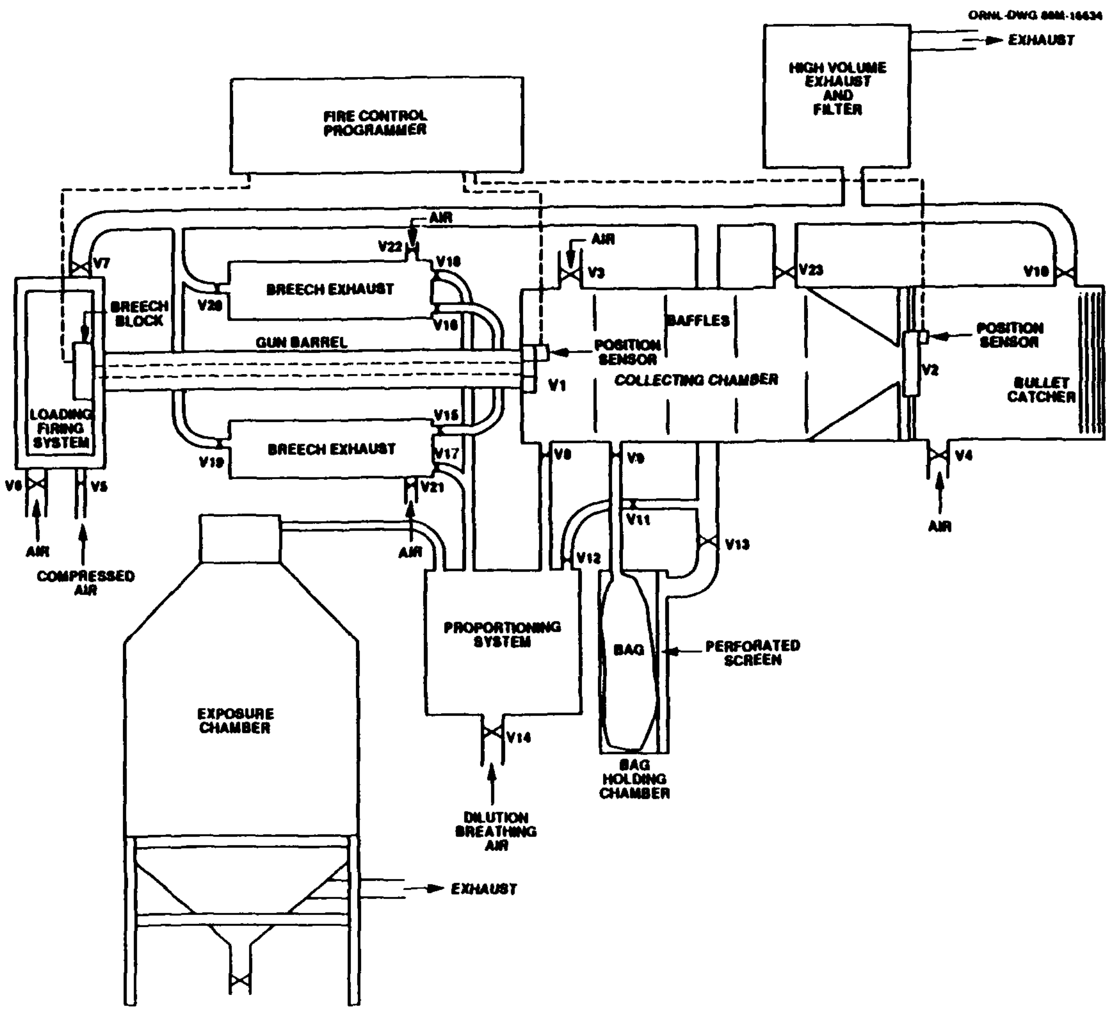

Figure 1: Schematic Diagram of Gun Exhaust Collection and Distribution System

critical surfaces would be made, in order to minimize absorption of vapors and particulates on the internal surfaces of the system.

For study of breech-only exhaust products, the muzzle exhaust is discarded, and small chambers designed for collection of the breech products are filled and used to supply the proportioning system. If muzzle-only products are desired, then the collection chamber is sealed immediately after firing, and the breech gases are exhausted.

Most inhalation exposures are likely to be conducted with a constant concentration exposure atmosphere. However, the system proposed is sufficiently sophisticated that a variable concentration exposure atmosphere could be provided. This would be accomplished by programming of the carbon monoxide monitoring feedback circuit described below. Alternatively, an intermittent exposure could be achieved, merely by flushing the contents of the CDS directly into the exposure chambers without mixing with dilution air. Since provision of a constant concentration atmosphere is the more challenging case, that option is described in detail below.

Details of the individual sub-systems of the collection/distribution system (CDS) are provided below. The general descriptions are for a generic system. Specific examples, where they pertain to either the small rifle system or the 30 mm cannon system, such as chamber volumes, are discussed where appropriate. A list of potential component suppliers is provided in Appendix A.

5.3.2 Breech Assembly

The breech assembly and firing/loading system is enclosed in a housing that may be pressurized with air. The enclosure should be sized so as to be able to contain a full load of ammunition required for a given exposure sequence. Otherwise, a more elaborate sealing system would have to be developed to admit ammunition stored at atmospheric pressure. After the gun is fired, the breech exhaust is trapped inside the barrel and empty cartridge from the round. After the cartridge is fired, the air pressure from the pressurized housing around the breech must be sufficient to sweep the breech gases through the barrel into the collecting chamber. Turbulence of the air around the brass opening will draw some of the breech gases from that volume.

However, as a significant fraction of the breech exhaust is contained in the spent cartridge, a system designed to purge the case before extracting would be useful. The approach presented above for pressurizing a housing around the breech and chamber suffers because the cartridge case forms a seal in the chamber and the seal is maintained until the cartridge case is nearly out of the chamber and ready to fall away. There is little time for the air to sweep the inside of the empty shell case, which would result in significant losses of breech exhaust when the case is ejected. Another approach is presented in Figure 2. This approach incorporates an air jet through which purge air may be jetted into the case. To prevent clogging of the jet opening and also to reduce the requirement for valves which function at extremely high pressures (20,000 to 80,000 PSI) in the chamber area, the jet opening is sealed by a sliding chamber block during firing. The sliding chamber block is moved slightly to the rear as the breech block is opened, revealing the jet and with the same motion moving the case in position such that the air may be jetted into the open case, thereby purging all breech exhaust. The sliding block and the case maintain a seal preventing the exhaust from escaping to the rear, so it is pushed through the barrel into the collecting chamber or through the side vents into breech exhaust collecting chambers. It is noted that the sliding block will have to be rather massive to withstand the pressures and that the surrounding

ORNL-DWG 88M-16635

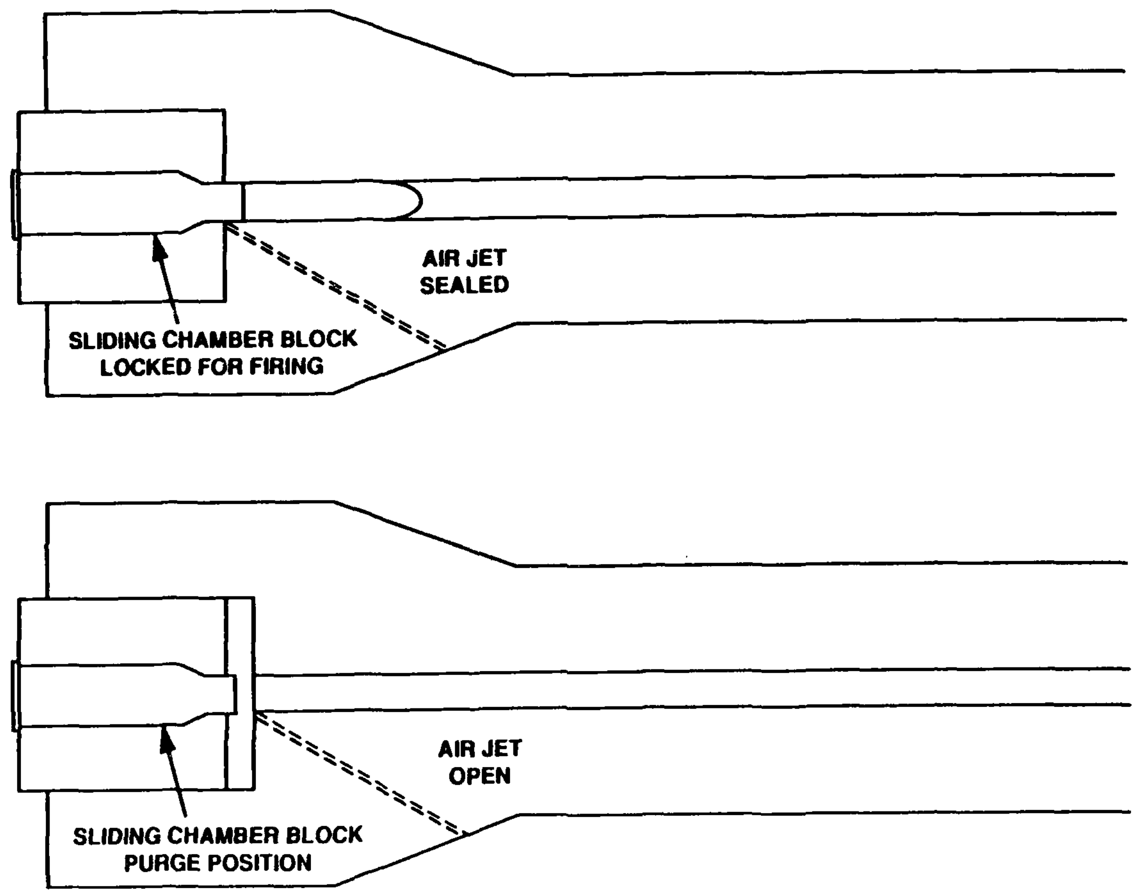

Figure 2: Schematic Diagram of Breech Spent Cartridge Purging System

chamber walls will need to be quite heavy. The action of the sliding block could be controlled by the breech mechanism and would have either a screw or sliding design. It is locked in the forward or firing position by the breech block and moved to the rear or purge position as the breech block opens. Only a slight delay would be required between the movement of the chamber block and ejection of the cartridge case.

A 30 mm cartridge case has an internal volume of approximately 300 cc and with the barrel volume a total of approximately 1.5 liters in the weapon. 10 to 15 liters of high pressure air could be quickly injected into the case purging both the case and the barrel.

Another alternative method for capturing the exhaust emissions trapped in the spent cartridge would be to allow the casing to be ejected into the loading chamber. However, this may result in some losses of the emissions, which would diffuse into the barrel prior to ejection.

If only breech exhaust is desired for study, valve V1 (Figure 1) at the end of the gun barrel must be closed immediately after firing and the breech exhaust purged through the barrel and into one of the small breech collecting chambers through one of the valved side vents from the barrel. For the firing of an M-16 rifle, the smallest rifle likely to be fired in such a system, the chambers would be approximately 1 L in volume, and could ultimately supply, downstream of the proportioning system, 1 L/min. of diluted breech exhaust at 2000 ppm CO on a one minute firing cycle for nose only exposure of rodents. For the 30 mm cannon with a 53 g propellant charge, the volume of the breech chambers would be about 30 L. In this case, the firing rate would have to be increased to once every 30 seconds to provide an adequate quantity of exhaust to permit whole body exposures of animals at flow rates through the inhalation chambers of 500 L/min. with a CO concentration of 2000 ppm. Two chambers are provided and are filled and emptied alternately, as it is expected that the total amount of breech gases and particulates will be relatively small for any gun and more rapid firing will be required. By alternating between the two chambers, as one chamber is being emptied into the exposure system the other chamber may be purged and refilled by the next firing sequence. Because of the small quantities of breech exhaust, the volume of that, relative to the dead volume within the proportioning system, may be sufficiently small as to mandate a specially designed proportioning system if breech-only exhaust evaluations are expected to be a major aspect of the toxicologic evaluations.

5.3.3 Main Exhaust Collection System

Muzzle gases and particulates will be collected in the primary collection chamber as the round is fired through the chamber with muzzle gases expanding rapidly into the chamber. In general, all surfaces which are exposed to the gun exhaust should be either Teflon or stainless steel. This should act to minimize artifactual chemical reactions, as well as minimize absorption on surfaces. Warming the surfaces may also be necessary to reduce this latter phenomenon. Baffles, as used by Snelson et al (1983) will help in holding the gases in the first chamber and absorb part of the shock wave from the firing. In general, the CDS must be fabricated from relatively thick-walled metal, so as to mitigate the effects of any muzzle flash. Valve V4 in the second chamber is open during firing to permit the escape of air as the expanding gases force the air from the first chamber. Some of the muzzle exhaust will be lost into the second chamber as well, but it is expected that the bulk of the gases and particulates will expand and be trapped in the first compartment. Some investigators have fired guns into a partially evacuated chamber, in which case the system may be closed to the atmosphere. However, by partially evacuating the chamber, the oxygen content of the atmosphere is decreased, which may significantly affect the chemical reactions in the muzzle blast and thus the ultimate chemical composition of the muzzle gases. Therefore, it is preferable to open the valve at the expense of losing a small fraction of the muzzle exhaust. By using a tracer gas in a series of separate experiments, losses could be determined rather accurately.

Valve V1 through which the gun is fired is expected to be a ball valve, similar to that marketed by Gemini Valve Inc. This is a stainless steel/teflon ball valve, pneumatically activated, with a spring return. The valve may be operated as normally opened or normally closed. In this case, it will be preferable to use the normally open mode. If the pneumatic system were to fail, the valve would return to an open position and prevent damage to the system if a round were to be fired. For the small rifle generator system, the valve would be a 1" ball, with a 2" ball required for a 30 mm cannon system.

A check for firing position (open position) of valve V1 and V2 must be provided. A system such as a light beam or position sensor will be essential. Miniature retro-reflective sensor assemblies utilizing fiber optics and infrared source/sensing systems would detect valve shaft movement and position and provide logic signals to the firing programmer. A reflective scanner such as the Skan-A-Matic S51101 should be adequate. The firing programmer would require a non-reflected signal from both sensors, indicating both valves were open, before a command to fire the gun could be given. Because they could measure valve position outside the collection chamber, these systems would not be exposed to the high shock waves inside the chamber.

After the muzzle and breech exhaust are trapped in the primary collecting chamber, they must be blended by means of a fan system. The air must be stirred gently so as not to cause impaction of particles on the surfaces. The gentle mixing may mean that the exhaust is not completely mixed. However, the design of the proportioning system is such that it can easily compensate for exhaust inhomogeneity and still provide for a constant concentration output.

After mixing, the exhaust, which has been diluted substantially just through mixing with the contents of the primary collection chamber, is drawn into the proportioning system, where its CO content is continuously monitored. The exhaust is diluted further to a specified concentration. The concentration of the diluted exhaust in the primary chamber will change continuously as it is drawn from the chamber, since replacement air will be drawn into the collection chamber and mixed with the remaining dilute exhaust. As a result of this continual dilution the proportioning system will gradually mix less and less air with the diluted exhaust. The proposed marker for concentration of the exhaust material is carbon monoxide (CO), as it is perceived to be the most toxic of the major components and is relatively easy to monitor.

For the larger gun system, a typical primary collection chamber might have an internal volume of 1 cubic meter (3 m long x 65 cm i.d.). Assuming that a 30 mm round contains 800 grains (52.5 g) powder, and that CO is produced at 40 mole percent in the 900 liters per kg powder burned, and that the gases are collected with 90% efficiency, then the initial primary chamber concentration of CO will be ca. 17,000 ppm. In order to achieve a 2000 ppm CO concentration downstream of the dilution system, an initial flow from the main chamber to the proportioning system of 60 L/min. will be required to maintain a flow of 500 L/min. to the animal exposure chambers. Filling the bag chamber (see below) at a rate of 100 L/min. during the second minute of the cycle will draw additional exhaust from the chamber. At the end of 3 minutes, prior to switching to the feed from the bag chamber entirely, flow from the main chamber would have increased to 75 L/min., and the CO concentration would have dropped to ca. 12,000 ppm.

At the other end of the spectrum, if an M-16 were used to generate exhaust for the small arms system, a typical primary chamber volume would be 250 L (1 m x 18 cm i.d.). A 5 round burst (1.7 g powder per round) with 80% collection efficiency would result in a chamber concentration of CO of about 10,000 ppm. On a two minute exposure cycle, over the first 30 seconds, the chamber contents would be withdrawn at a rate of 115 L/min., resulting in a CO concentration of ca. 8000 ppm. After the bag chamber was filled, that level would fall to 3200 ppm.

5.3.4 Bullet Catching Region

The projectile exits the main collection chamber and enters the bullet catching region. Figure 1 depicts this region as a closed volume, with only valve V4 permitting contact with the outside air. In all likelihood, this region would consist of a cylinder which leads within a few inches of the face of the bullet catcher, but is not actually sealed from the atmosphere. It is likely that the need to change the position of the catcher with time (see Section 5.8) would make sealing the system to the outside air impractical. However, there would be a need to flush this region after each firing, because it would contain aged exhaust which could potentially mix with the fresh exhaust generated from the next firing.

Essentially, two types of projectiles might pass through valve V2. These are discussed in some more detail in Section 5.4. Briefly, for the conventional solid projectile from the small rifle, a 1" or 2" ball valve would be satisfactory. For the 30 mm cannon, firing a solid projectile or the shot-filled sabot, a larger valve would be required. A six inch gate valve, as provided by DeZurik Inc. should be satisfactory. This valve is also pneumatically operated and spring returned. It is constructed of stainless steel with all exposed surfaces being either stainless steel or Teflon and costs approximately $2150. An interesting alternative to the muzzle gate valve is a valve known as the Iris diaphragm valve. In this unit, a rubber or coated fabric sleeve opens and closes similar to the iris of a camera in response to torsional forces exerted on the ends of the sleeve. The valves are used in the process industries for the flow control of powders, abrasive slurries and other difficult streams. The potential advantage as used for the muzzle valve would be that if it were accidentally in the closed position at firing, it could pass a projectile without some of the consequences that might develop if the valve was a rugged metal gate valve. Preliminary inquiries indicated a Mucon-Kemutec type G8 valve with pneumatic operator and Teflon coated nylon sleeve might be practical.

The various types of bullet catchers suitable for these applications are discussed in Section 5.8.

5.3.5 Bag Containment System

For most inhalation exposures, animals should be exposed to a continuous concentration of reasonably fresh diluted exhaust. However, the time required to evacuate the primary collection chamber after each firing, to prevent unsuitably aged exhausts to be mixed with fresh exhaust, and to reset the valves, is such that there would be a finite period of time in which no exhaust is being delivered to the exposure chamber. This would result in a varying exposure, the degree of which would be dependent on the flow rates into the chamber. One alternative is to maintain two entirely separate generation and collection/distribution systems, which would alternate their operation, such that as one was being evacuated, the other would be filling with exhaust. This would dramatically increase the cost of the facility. The other alternative is have a small chamber which is filled with the diluted exhaust products, from which can be drawn exhaust products during the evacuation of the main chamber. However, when the exhaust is moved from the main chamber to another smaller chamber by vacuum or by air pressure, the atmospheres will be diluted in each chamber. That is, to permit removal from the larger chamber, air must replace the volumes withdrawn, diluting that atmosphere. The smaller chamber, unless evacuated prior to filling (not practical in this situation), will be filled with air, causing a second dilution into the entering atmosphere. At this point, the atmosphere would be diluted to the point where it may, in some exposure situations, be toxicologically useless. Ideally, the material should be transferred without having to undergo a second dilution. A piston or bellows diaphragm system could be employed to avoid the second dilution, however the volumes needed in this situation are not readily adaptable to piston or diaphragm. The bag system as shown in Figure 1 is the proposed alternative.

In design, the bag should have a volume somewhat greater than the chamber within which it is mounted. This is to prevent bursting the bag by overfilling. The bag is contained within the chamber and separated from a side chamber by a perforated screen. It is emptied and collapsed by drawing all air from inside the bag through valve V11 with valve V14 open to permit air to enter the chamber outside the bag. After the primary collection chamber is filled, the bag chamber is filled by closing valves V11 and V14 and opening valve V13 and V9. Air from around the bag is drawn through the perforated screen which expands the bag, drawing the exhaust mixture from the collection chamber. By closing valves V13 and V9 and opening valve V12 and V14, this material may then be drawn from the bag chamber to the proportioning system and into the exposure chamber. Thus, the bag chamber is used to supply the proportioning system while the collecting chamber and gun are purged and the next round fired. Tedlar bags as supplied by SKC Inc. have proven reliable for repeated use and should serve well in this situation. Frequent (daily) changing of the bag would be recommended.

5.3.6 Exhaust Proportioning System and Firing Programmer

Control of the rate of removal of the contents of the primary (and bag) chamber would be accomplished through the use of a proportioning valve. Essentially, a constant flow would be drawn on the exposure chamber system, which would in turn draw a constant volume of diluted exhaust downstream of the proportioning valve. The valve would be controlled, following the firing, so as to provide for a proportionately greater fraction of the atmosphere coming from the primary collection chamber as it becomes increasingly diluted with incoming air. Control would be achieved through a feedback loop, in which the level of carbon monoxide (CO) would be monitored by a non-dispersive infrared (NDIR) analyzer. That information would be sent to a three-mode electronic controller into which had been programmed the delay in response time due to the response rate of the analyzer and the dead volume in the system. The use of a feedback loop obviates the need for thorough mixing to achieve a completely homogeneous atmosphere of exhaust in the collection chamber prior to the exhaust's removal from the chamber. The latter would require the use of fans rotating at high speed inside the chamber which could cause impaction of exhaust particulates on the housing walls and prevent their inclusion in the exposure atmosphere. The use of an NDIR CO monitor has been chosen over other potential monitors because of the reliability of the instrumentation and the rapidity of its response.

A vital part of the system shown in Figure 1 is a firing programmer, which has been depicted in more detail in Figure 3 and which would serve to properly sequence various functions within an operating cycle. The firing programmer would consist of a commercially available programmable logic controller (PLC) with some custom features added for interfacing with the dilution control loop. PLC's such as the Texas Instruments Model 510, or the Allen Bradley SLC 100 should be adequate as a basic system. The programmer would (1) provide an electrical trigger for re-firing as dictated by the falling CO level, (2) synchronize the opening and closing of the muzzle ball valve with the firing, (3) operate valves to provide make-up or "sweep" air for the muzzle and/or breech areas, and (4) provide certain safety interlocks in the system. A typical interlock would be one actuated by a switch on the muzzle valve to absolutely lock out the possibility of firing unless the valve were fully open. While the control system for the valve would

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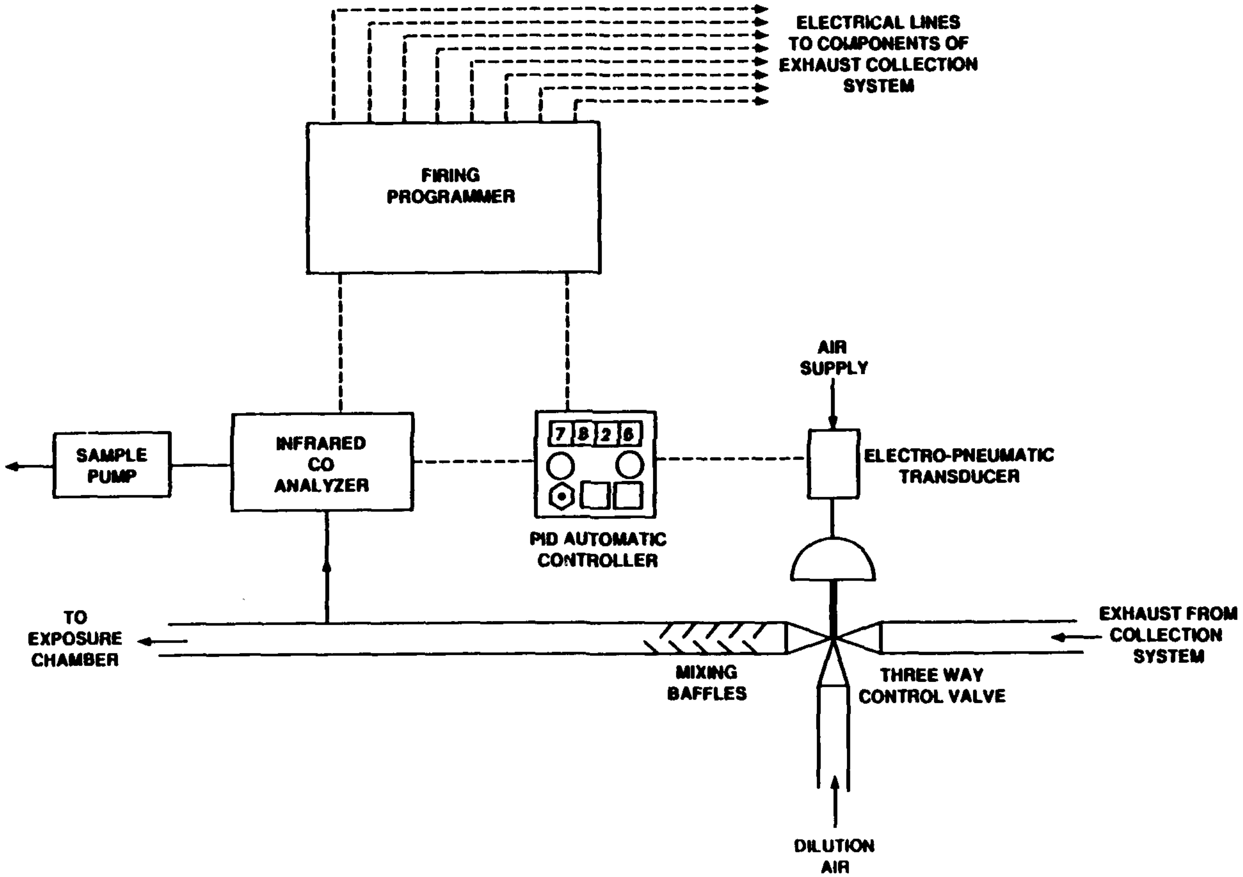

Figure 3: Schematic Diagram of Firing Controller and Proportional System

be highly reliable and the valve would normally fail "open" (air-to-close), an interlock would nevertheless be prudent to handle the very remote possibility of internal mechanical binding or jamming. Other interlocks would probably be incorporated based on other safety considerations in a given installation. The interval between firings would be determined empirically by the volume of gas generated by each firing, the volume of the system, the flow rate and desired concentration of the mixture going to the exposure chamber.

In actual practice, it may be that a signal other than only the CO level would be employed to trigger re-firing. A signal derived from the electronic controller, indicating that the eproportioning valve was approaching its extreme position for minimum dilution air, might provide an "earlier" and more optimum signal for monitoring constant CO level. The firing programmer would provide the means of using this signal and/or actual CO level to trigger re-firing. The programmer might also provide a bias or "feedforward" step signal to reposition the proportional valve by a finite amount immediately on re-firing. While the 3-mode electronic controller will provide rapid, continuous modulation of the proportioning valve in response to CO level, a step bias signal may need to be integrated into the control system immediately following firing, to prevent a sudden surge in CO level and resultant upset in the control loop. There are a number of ways the firing programmer might provide this signal; however, the most desirable specific control architecture can probably be specified only after preliminary development of the system.

Feedforward control systems using pneumatics are sometimes used in the process industries where sudden load changes occur in control loops with medium to long time lags. A typical system would incorporate a multi-function computing relay (such as Moore Products Model 68-1, Moore Products, Spring House, PA 19477) which normally would allow a sensor for the slow control loop to maintain control but would also allow a "temporary" signal from outside the loop to override the normal signal to provide an anticipatory action based on some external event. Some systems use a so-called "auctioneering" relay which selects the higher of two signals and positions the final control element accordingly. It is no doubt possible to accomplish the feedforward electronically, but the exact method and hardware selection would depend on the particular electronic controller used for the CO loop control.

5.3.7 Example Firing Sequence

An example of a firing sequence is presented showing the sequence and operation of the valves in the system. The entire sequence would have to be very carefully timed in order that collecting chambers are purged before collecting exhaust materials and valves through which projectiles pass are truly open before firing. Fail safe monitoring for the latter is imperative. A four minute exposure period was chosen as a typical example. After chemical evaluation of the exposure atmosphere, another period may prove more suitable. The sequence also assumes an exposure to mixed breech and muzzle exhausts.

Firing Sequence
Based Upon a Four Minute Exposure Cycle

Time	Action or state
0 sec.	All chambers contain only clean air All valves closed Round is in gun chamber
1 sec.	Signal is given to open V5 in order to pressurize housing around loading and firing mechanism. Signal to open V1, V2, and V4 (Verify that V1 and V2 are open with fiber optic sensor)
2 sec.	Fire round (If sensor detects V1 or V2 closed, then firing is prevented.) Gases and particulates expand in collection chamber. Projectile passes through V1 and V2 to bullet catcher.
3 sec.	Signal eis given to close V2 and open V10, permitting purging of bullet catching region. Sliding block inside breech is allowed to be pushed back, exposing air jet, which flushes inside of spent cartridge.
4 sec.	As spent cartridge is ejected, high pressure air sweeps breech exhaust through barrel into the collection chamber.
5 sec.	Signal is given to close V1, V5, and to open V8, V3, V11, and V14. Exhaust mixture is drawn from collection chamber through V8 to the proportioning system. Replacement air is drawn into the chamber through V3. In the proportioning system, the CO concentration of the incoming mixture is monitored and the mixture is further diluted to the desired CO concentration. Bag in the bag chamber is deflated.
65 sec.	Signal is given to close V11 and V14, and then open V9 and V13. Bag begins to fill from collecting chamber diluted only by air admitted through V3.
180 sec.	Signal is given to close V8, V9, and V13, and to open V1, V2, V6, V7, and V12. Flow through proportioning system begins from bag chamber. Collection chamber is purged through V2 and V10, and loading/ firing system is purged through V7

235 sec.	Signal is given to close V3, V6, V7, and V10 after collection chamber and breech housing purging have been completed.
238 sec.	Round is loaded and breech block closed.
240 sec.	Signal is given to open V5 and V4, and to verify open position of V1 and V2.
241 sec.	Breech housing is pressurized.
242 sec.	Fire round.

Repeat the above cycle.

5.4 SCALED-DOWN AMMUNITION FOR 30 mm GENERATION SYSTEM

Clearly, the cornerstone of the effort to generate large-gun exhaust from a smaller weapon is ammunition whose projectile mass, propellant load and type, burn rate, and primer and ignitor are just smaller versions of those which exist in a larger system. Essentially, these rounds would be slightly miniature versions of those used in 105 and 155 mm munitions. The chemical composition of the materials likely to contribute species to the gun exhaust would be identical to those which exist in the larger gun. These would include the propellant, the ignitor, the primer, and the projectile material itself. The latter is important because the hot gas erosion of the projectile often contributes to the inorganic species present in the exhaust. The choice of a 30 mm projectile size was made because the effort required to develop a system to mimic the performance of a larger munition increases in a manner which is inversely proportional to the size to which the test munition is being scaled (Hanchak, 1987). For example, it would be impossible to load the same diameter propellant grains which are present in a 105 mm round into a 7.62 mm round, simply because they would not fit. In addition, it would be impossible to insert the appropriate ignitor assemblies into the smaller cartridge. In other words, if the difficulty of stopping the projectile in a routine, repeated use situation is weighed against the difficulty of developing a scaled down munition, then 30 mm seems to be the point at which both concerns can be balanced.

An obvious beginning for such a development effort is to start with the projectile mass, and reduce the amount of propellant in the scaled down round proportionately to the projectile mass. Clearly, there are a number of additional considerations. These include the ability of the 30 mm gun breech and barrel to withstand the pressures developed by the burning propellant, the time of travel of the projectile down the barrel, which controls the time at which the pressure precipitously drops to atmospheric, the burn rate of the propellant grains, etc. A number of these factors have been discussed in Section 2.1 of Volume 1 of this report (Ross, et al, 1988).

A number of experts who were consulted in the process of compiling this report indicated that such a development effort should be possible (Stiefel, 1986; Hanchak, 1987; Domen, 1988). We then approached Radford Army Ammunition Plant, Radford, Virginia as possible suppliers of the munitions. A spokesman indicated that such a goal seemed reasonable of accomplishment, but that a concrete request or purchase order would have to be forthcoming before Radford could respond formally or provide a cost estimate for the development work or eventual supply of the downscaled ammunition (Daniel, 1987). Thus, for the purposes of this report, we have indicated that such ammunition can be developed and sufficient quantity supplied for both chemical characterization studies, and routine exposure studies.

One alternative which should be considered if difficulty in stopping a conventional 30 mm projectile is encountered is to replace the projectile with a steel shot-filled sabot. Filled with an appropriate mass of material, it would require the same amount of energy to propel it toward the target. Once in flight, the sabot would come off, and individual shot pellets would strike the target, rather than one projectile. The chief advantage of this approach is that the kinetic energy of the projectile is dissipated over a larger surface area. The approach has several disadvantages. Most importantly, the material contacting the gun barrel would not be the same as that in a real projectile, and thus might alter the composition of the particulates generated as part of the exhaust. Secondly, errant pellets in the CDS could do considerable damage to it. Finally, a larger gate valve would have to be used at the end of the primary collection chamber in order to accommodate the larger pattern of the shot.

5.5 SAMPLING AND ON-LINE ANALYSIS SYSTEMS FOR CHEMICAL CHARACTERIZATION STUDIES

5.5.1 Introduction

Based on the constituents produced from gun and rifle firings which have been documented previously (Ross, et al, 1988), it appears that the exhaust products can be categorized into four groups: reactive and low molecular weight gas phase components, organic vapor phase components, organic particulate phase components, and inorganic particulate phase components. A review of all of the potential instrumentation and sampling equipment for collection and analysis of all possible gun constituents is beyond the scope of this document. Nader, et al (1983) have reviewed instrumentation for on-line analysis of airborne vapors and gases. Lippmann (1983) has reviewed the collection of aerosols via filtration. Jenkins and Guerin (1987) have described general sampling considerations for collection of environmental tobacco smoke aerosols which may also apply to the collection of any aerosol which contains semi-volatile organics, such as gunsmoke particulates. And Harrison and Perry (1986) have reviewed a number of considerations for air pollution sampling which are pertinent to the collection of dilute gunsmoke exhaust. The purpose of the discussion below is to briefly describe practical approaches to the collection and analysis of the major exhaust constituents and class fractions.

5.5.2 Reactive and Low Molecular Weight Gases and Vapors

A survey of most of the reported literature on gun exhausts indicates that the major gas phase constituents are carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), hydrogen (H_2), ammonia (NH_3), the oxides of nitrogen (NO_x), and hydrogen cyanide (HCN). For routine characterization studies, it is likely that a single stainless steel probe would be inserted through a port in the diluted exhaust stream downstream of the CDS proportioning system, and that a number of instruments would pull aliquots of the sampled stream.

The carbon monoxide analyzer employed would be a Beckman Model 865 non-dispersive infrared (NDIR) unit or equivalent having dual ranges of 0-300 and 0-3000 ppm CO. This particular instrument is a classical full size dual beam unit with excellent specificity. Its rejection ratio against CO_2 and water vapor, as well as all other species anticipated in the exhaust stream, is better than 20,000 to 1. The 90% response for this instrument is typically ten seconds at a sampling rate of one half liter/minute. Field calibration can be made at the beginning and close of each operating day using two known bottled gas standards (200 and 2000 ppm) of CO in air.

The carbon dioxide analyzer employed would be a similar non-dispersive infrared unit, with a span range of 0 - 500 ppm and 0 - 2500 ppm. Response parameters would be similar to those for the CO unit. It would be standardized in a similar manner. Methane can also be determined by NDIR instrumentation, with similar response times and specificities.

There are two available approaches for the determination of ammonia. One is to employ an NDIR unit with a dual range of 0 - 300 ppm and 0 - 1500 ppm, similar to those described above. This is likely to be somewhat more specific and have fewer interferences than the electrochemical unit described below. It is also about twice as expensive (ca. $7000). Another approach is to use an electrochemical sensor system, similar to that described for the determination of HCN. Its range is limited to 0 - 30 ppm, which is suitable for low concentration measurements. Its cost is about $3000.

The HCN analyzer recommended is a Sensidyne Type 7010671-3 Toxic Gas Sensor (Sensidyne, Inc., Largo, FL) with Sensidyne Model 1000 readout/controller or equivalent. The core of the system is a small controlled potential electrolysis cell in which the gas to be measured diffuses into the cell through a permeable polytetrafluoroethylene (PTFE) membrane. An initial range setting for this particular instrument 0-100 ppm HCN, although more sensitive range settings are possible. Interferences from other gases, as stated by the manufacturer, are very minor to non-existent for the species anticipated in gunsmoke exhaust. Response time (90% full scale) is stated by manufacturer as 20 seconds but has been found in our laboratory to be closer to 40-60 seconds in actual practice. Twice daily calibration can be performed in the field using the manufacturer's "ampoule calibration kit". In this kit an ampoule of accurately known HCN gas is broken and the gas dispersed in the known volume of air in a container designed to fit tightly around the sensor.

The determination of hydrogen is by no means straightforward. One approach which has worked well for the continuous analysis of hydrogen is the use of thermal conductivity. Although the technique is non-specific, and thus the analyzer would respond to any substance which possesses a different thermal conductivity from the carrier medium, the difference between the thermal conductivity of H_2 and other vapors is such that this approach has proved successful for a medium as complex as cigarette smoke (Gayle, et al, 1979). Some development work would be required to validate this approach. One tactic may be to take continuous, discrete samples, pass them through a gas chromatographic column, which would retain other vapor phase constituents, and then on to a thermal conductivity detector.

The NO/NO_x analyzer recommended is a Beckman Model 951A (Beckman Industrial Div., Rosemount, Inc., La Habra, CA) or equivalent using a chemiluminescent procedure in which nitric oxide is reacted with ozone to produce electronically excited nitrogen dioxide molecules. As these revert to ground state, photons are released and measured by a photomultiplier and associated electronic circuitry. When it is desired to measure total oxides of nitrogen ($NO+NO_2$), the sample is first routed through a converter where the NO_2 component is converted to NO. This instrument is widely used for atmospheric analysis and appears to be quite dependable. The unit has seven ranges covering 0-10 ppm to 0-10,000 ppm. Calibration of the unit can be verified prior to each day's operation using a bottled gas standard containing both NO and NO_2. Response time (90% full scale) of the instrument is approximately 20 seconds.

With the exception of the NO_x analyzer, which has a built-in pump, all of the systems require that a sample be drawn through the analyzer unit. This can easily be accomplished by either placing a small diaphragm pump downstream of each unit, or placing a larger pump on a manifold, with the flow through each unit being controlled by a critical flow orifice.

5.5.3 Organic Vapor Phase Constituents

The range of volatilities of vapor phase compounds likely to be present in the gunsmoke is very large. Classical approaches to the sampling of such constituents involve collection on traps filled with a single sorbent resin, such as Tenax-GC (Sheldon, et al, 1985). However, it is likely that a number of trace organic components will break through and not be retained on the trapping material. Thus, the trapping system recommended for use in the gunsmoke facility is a triple sorbent unit, similar to those reported previously (Higgins, et al, 1987; Williams and Chan, 1987). The trap would consist of a stainless steel tube, 20.5 cm long x 0.46 cm I.D., packed with three sorbent materials. Approximately 1.7 mL of 35 - 60 mesh Tenax-GC (Alltech/Applied Science) is backed with approximately 0.8 mL of 20-40 mesh Carbotrap (Supelco, Inc.), an uncoated carbon molecular sieve, which is, in turn, backed by 0.3 mL of Ambersorb XE-340 (20-60 mesh, Rohm & Haas). After conventional resin cleaning procedures prior to construction, the material is packed in the stainless steel tubes, separated by small plugs of silylated glass wool, and desorbed for several hours at 270°C with helium at a flow of 20 mL per minute. Desorption flow is always in the direction of the Ambersorb being the upstream end, while collection flow is in the reverse direction. In this manner, constituents breaking through the Tenax are retained by the Carbotrap, and so forth. An additional recommended approach is to employ commercially available Carbotrap 300 sorption tubes. Small diaphragm pumps can be used on each cartridge through which a sample is pulled.

5.5.4 Organic Particle Phase Constituents

A number of high molecular weight organic compounds, such as polynuclear aromatic hydrocarbons (PAH), have been identified in the particle phase of gunsmoke (Ross, et al, 1988). These materials can best be collected using high volume air samplers drawing through filters of non-reactive media, such as Teflon-coated glass fiber. Non-reactive media are especially important in those cases in which oxides of nitrogen are likely to be present with the PAHs, as significant quantities of artifact compounds can be formed after the PAHs have been collected (Lee, et al, 1979). Also, studies in our laboratory with the particle phase generated from the firing of test rocket motors indicated that the particles could clog single stage filtering systems. Thus, the use of a dual stage particle filtering system is recommended. Such could be accomplished with a Staplex Model TFIA Air Sampler fitted with an 8 x 10 inch filter holder or equivalent, with the filter material being a sandwich of a 10 - 15 um cut-off Teflon coated glass fiber filter (Pallflex T015A) and a 0.3 um Teflon-coated glass fiber filter (Pallflex T60A20). The filter holder would be connected to the duct leading to the inhalation chamber, of the chamber itself.

There is an increasing body of evidence to indicate that under high volume sampling conditions, relatively non-volatile compounds, such as PAHs or polychlorinated biphenyls (PCBs), can be evaporated out of the particulate matter on which they are adsorbed and transported in the vapor phase (Thrane and Mikalsen, 1981; Griest et al, 1988). In such cases, the filter media should be backed with foam adsorbent (Smith et al, 1986), or resin cartridges, such as that which is used in the modified EPA Method 5 sampling train (EPA, 1986; Hollod and Eisenriech, 1981). For example, polyurethane foam plugs can be cut to fit the inside of the filter holders, in order to collect the volatilized constituents.

5.5.5 Inorganic Particle Phase Constituents

Metallic constituents of the gun exhaust are predominantly a product of the erosion of the gun barrel and the projectile by hot gases. The metallic content of particles in the exhaust can be significant, and certainly needs to be determined. Because of their high background levels of trace metals, glass fiber filters are not recommended for collection of particulates for inorganics determinations. Instead, an organic based membrane or fiber filter, such as cellulose ester or Teflon, is used. For example, a 0.5 micron polytetrafluoroethylene (PTFE) 47 mm filter (Millipore FHLP-047, Millipore Corp., Bedford, MA) could be used for collection of a sample for metals analysis. The filter holder would be a BGI Type F7 (BGI, Inc., Waltham, MA) with internal support screen. Sample rate through such a filter can be as much as 18 liters/minute, depending on the pumping system used.

5.5.6 Particle Size Determination Instrumentation

Determination of the distribution of particle sizes in a complex matrix can be accomplished by several methods. The two methods most commonly used are cascade impaction and optical particle counting. The cascade impactor (CI) instrument draws an air sample through a small orifice which is designed to give the air stream a velocity at which a particular range of particles will be carried by their momentum to impact upon the stage and smaller particles will flow around the stage with the air stream through progressively smaller holes which impart progressively increasing velocity, causing progressively smaller particles to impact upon successive stages. The collected residues can then be chemically analyzed or gravimetrically determined for mass fraction, i.e., weighed. CI instruments generally contain several stages with a terminal, downstream collection media, and a final filter to collect any undeposited aerosol/particulate matter. Personnel aerosol samplers, which collect an inhalable fraction on an impaction stage and the respirable fraction in a filtration stage, have been described (Bright and Fletcher, 1983). Particle losses in an impactor, generally referred to as wall losses or interstage losses, occur due to deposition of particles on surfaces other than the impaction plate. Currently, no theory exists to predict these losses. Thus, they must be determined experimentally using standard test aerosols and comparative test methods (Marple and Willeke, 1984). On the other hand, the optical particle counter (OPC) measures the particle size distributions in real time so that aerosol data may be obtained fairly rapidly and semiautomatically. The OPC determines the optical diameter of the particle based on the intensity of light scattered by individual particles. However, the intensity of the light depends upon the optical properties of the particle and cannot be directly related to aerodynamic diameter (Willeke and Liu, 1976).

While the CI instrument does measure the aerodynamic diameter of the sample, as deposited, the measurement is not performed in real time. Reactive particles, evaporation effects, coalescing growth, and ricocheting particles can lead to errors in measurements of complex aerosols. Because munitions produce hot, partially oxidized gases and potentially reactive particulate matter, other particle sizing techniques may be more useful for gunsmoke characterization. For example, laser-actuated, acoustic relaxation techniques may be utilized for measuring aerodynamic diameters of particulate smokes in real time to supplement or augment CI and OPC measurements.

A single particle aerodynamic relaxation time (SPART) analyzer has been utilized in our laboratories for monitoring process aerosols that are formed by gas-phase reactions. Also, aerosol formation by various nucleation processes (e.g., heterogeneously or homogeneously) may be studied with the SPART technique. This instrument, developed by University of Arkansas experimenters (Mazumder and Kirsch, 1977), consists of three basic components: (1) a laser Doppler velocimeter (LDV), (2) an acoustic chamber, and (3) electronic signal and data processing circuitry. The LDV is used to monitor the oscillations of an aerosol particle in an applied acoustic field. The aerosol sample is drawn inside the acoustic chamber where the sensing volume of the LDV is located. The particle motion will lag behind the acoustic excitation by an amount that depends upon the particle's aerodynamic diameter. This phase lag may be measured by a fast data processor which allows the computation of the particle's aerodynamic diameter. The instrument can accommodate aerosol flow rates of only 200 particles per second, however. While the dynamic range of size fraction is wide (~0.3 to 10.0 micrometers), the "sharpness of cut" is not as precise as is obtainable with well constructed CI instruments. Moreover, calculations of mass concentration are based on the assumption of a spherical particle of unit density. All of these instruments may be useful for gunsmoke characterization. Also, some other instrumental techniques such as differential mobility (Alofs and Balakumar, 1982), electrical aerosol analysis (Liu and Whitby, 1974), condensation nucleus counting (Sinclair and Hoopes, 1975), and piezoelectric crystal mass-loading (Sem and Tsurubayaski, 1977), measurements may be applied to provide meaningful aerosol data (Lore and Skeen, 1985). For routine use in the gunsmoke facility, the most effective equipment for these types of measurements would seem to be a cascade impactor, since it seems unlikely that measurements would be made more than once per characterization run.

Portable, personal aerosol monitoring instrumentation has recently been developed by private industry with government support. This equipment has been tentatively approved by the federal authorities (U.S. Department of Labor, Mine Safety and Health Administration; Approval No. 2G-3532-0). The monitor analyzes respirable aerosol/particulate matter (0.1 to 10.0 micrometers in diameter) by a forward light scattering technique. This miniature, respirable aerosol monitor (MRAM) is described by the instrument manufacturer, MIE, Inc. (formerly GCA Corporation), as measuring the instantaneous, respirable aerosol mass concentration over the range 0.01 to 100 mg/m^3. Independent laboratories, government and industrial concerns are currently evaluating the MRAM instrument for personal monitoring applications, according to discussions with the manufacturer's technical personnel (Lilienfeld, 1986).

5.6 INSTRUMENTATION FOR ROUTINE GENERATION OR EXPOSURE MONITORING

Irrespective of whether any chemical or toxicological evaluation studies are being performed, any time that gunsmoke exhaust is being generated, there should be an independent determination of the concentration of the exhaust products leaving the CDS. This affords a real-time determination of the accuracy of the generation and dilution process, and acts as a reference point for the operator. The recommended approach is to monitor for both gas and particulate phases. Carbon monoxide is proposed for the gas phase constituent because it is present in rather large quantities, is relatively unreactive, and is important from a toxicological standpoint. Measurement of the particulate concentration is recommended as well. Because the particles are more prone to settling and impaction loses, a stable particle concentration should be indicative of consistent operation of the generation system. Thus, for routine monitoring of the chamber atmosphere or its inlet mixture stream(s), two instruments are suggested: (1) A continuous CO monitor and (2) A real-time aerosol monitor.

The CO monitor would be almost identical to the instrument specified for dilution control - The Beckman Model 865 Dual Beam Non-dispersive Infrared Analyzer (Beckman Industrial Division, Rosemount Corp., La Habra, CA). The dual ranges of 0-1000 and 0-5000 ppb together with its superior accuracy and long term stability appear to be well suited for this application.

For monitoring the chamber particulate concentration, a Model RAM-1 Real Time Aerosol Monitor (MIE, Inc., Bedford, MA) is recommended. This instrument is suitable for either portable operation or permanent installation and provides selectable ranges of 0-2, 0-20 and 0-200 mg/m^3. The unit features an internal air sheath in its optical system to prevent surface contamination and associated signal drift when measuring difficult "sticky" particulate mixtures. The particle size range of measurement provided is from 0.1 to 20 micrometers diameter. However, the instrument also features selectable impaction precollectors to provide response to respirable material only if that is desired.

Both the Beckman CO Instrument and the MIE Aerosol Monitor provide local digital and/or analog readout as well as voltage and current outputs. It is anticipated that these linear output signals would be recorded or fed to a data system or available computer for permanent records.

5.7 TOXICOLOGICAL CHARACTERIZATION CONSIDERATIONS

5.7.1 Introduction and Purpose

Methods for the toxicological evaluation of complex matrices such as gunsmoke have been reviewed in Volume I of this document. The purpose of this section is not to discuss a generic toxicology facility. Rather, it is directed toward a brief discussion of those aspects of the toxicology facility which may be directly affected by the unique nature of the gunsmoke being generated. The discussion below is divided into discussions of inhalation and non-inhalation exposures, including in vivo and in-vitro studies.

5.7.2 Inhalation Exposure of Live Animals

Inhalation exposure to multiphase aerosols is a complex undertaking (Dalbey and Lock, 1982; Kendrick, et al, 1976). Gun and rifle exhaust, because it consists of a number of reactive constituents distributed among the solid, liquid (aerosol droplets), and vapor phase, can easily be considered a complex aerosol for the purposes of this discussion. The nature of gunsmoke, as it relates to inhalation exposure, raises at least three important issues. These are discussed briefly below.

5.7.2.1 Degree of Exhaust Aging Suitable for Exposure

Humans are exposed to gunsmoke under a variety of conditions. From the firing of small arms from inside bunkers, where the exposure is predominantly breech exhaust only, to the firing of larger guns from inside battle tanks, where the immediate exposure may be breech exhaust, but where ventilation systems may draw aged and diluted muzzle exhaust into the crew compartment, the degree to which the various smoke components are allowed to stand prior to their use in exposure can affect their toxicological potency. Exposures may be essentially continuous or intermittent. Designers of other inhalation bioassays of complex aerosols, such as cigarette smoke, which can undergo chemical transformation over a short period of time, often go to great lengths to duplicate exact human exposure conditions as closely as possible. The exposure regimen is likely to be an issue which is discussed at great length by toxicologists directing the inhalation studies. It is also a factor which is likely to change from study to study, depending on the human exposure situation which the bioassay is attempting to model. Thus, it seems critical to the design of the exhaust generation and the collection/distribution system to provide for as wide a variety of firing sequences and cycle times as is possible. Based on the description in Section 5.5.7, it seems unlikely that a cycle time which is shorter than about 30 seconds would be practical, especially for the larger gun system. Longer cycle times, on the order of two to four minutes, would be utilized more frequently.

5.7.2.2 Utility of Nose-only vs. Whole Body Exposure for Rodents

In any bioassay in which the human exposure being modeled via inhalation, a decision much be made as to whether to expose animals via the most relevant route (nose-only), or via the logistically easier route of whole body exposure. In many cases, the amount of exhaust which can be produced will limit the available exposure options. For example, the firing of an M-16 rifle releases the gases from about 1.7 g of propellant. If the amount of CO produced is ca. 0.034 moles (2 moles/100 g propellant), and as much as 2.5% of the total exhaust is considered breech exhaust, then less than 11 L of diluted exhaust having a CO concentration of 2000 ppm can be offered for exposure.

Thus, it is critical to consider the strengths and limitations of each approach. The primary advantages of whole body exposure seem to be that it is relatively simple to perform, larger numbers of animals can be exposed simultaneously with minimal effort, and there is a large body of previous toxicologic data to which to relate the exposures in question. The major disadvantages are that for animals which preen, there will be a substantial oral dose of the particulates and the organic gas phase constituents which might confound the biological interpretation of the results (Jenkins, et al, 1983). This is especially significant for longer and sub-chronic studies. Also, the whole body exposures consume much larger quantities of exhaust, and make plethysmographic measurements much more difficult. The advantages of nose-only exposures are that only the target organ system (the respiratory tract) receives a significant dose. This is somewhat dependent on the type of containment used. For example, in some nose-only exposures in which the animals are placed in tubes which contain their bodies, the animals receive a substantial oral dose, because the smoke gets inside the tubes during exposure and deposits on the fur (Phelps, et al, 1984). In exposures where the animals' bodies are open to the ambient air, fur deposition is of a much smaller magnitude (Henry, et al, 1981; Henry, et al, 1985). Also, the amount of bioassayed material which is required for the exposure is much smaller. The major limitations are the greater degree of handling of the animals, and, if the animals are housed in tubes, the greater the body heat build-up. Also, the degree of restraint required for nose-only exposures is much greater, which makes them less suitable for long duration (multi-hour) exposures.

5.7.2.3 Considerations for Larger Animals

A number of inhalation studies have employed larger animals, such as dogs, rhesus monkeys, or baboons for assessment of the toxicity of complex combustion derived aerosols. Given the size of such animals, it appears that it would be difficult to produce adequate quantities of gunsmoke exhaust in which to perform whole body exposures, without considerably expanding the size of the generation system. For example, it would be difficult to place more than two dogs in a standard sized (1.4 m^3) chamber. Thus, respiratory tract-only exposures would seem to be mandated for larger animals. For dogs, cuffed tracheal cannulas (Brazell, et al, 1984) appear to be more comfortable than non-cuffed, since any irritants in the aerosol never contact the upper respiratory tract. For rhesus monkeys undergoing combustion aerosol exposure, masks which ucover both the nose and mouth seem to function well (Paule, 1987). However, the dual valve system used for intermittent exposure to marijuana smoke may not be required because the need to prevent the animals from defeating the exposure by blowing the smoke bolus out of the mask is absent. That is, given a continuously replenished atmosphere of gunsmoke, there is no way for the animal to get fresh air which has not been mixed with gunsmoke.

Many of the complex combustion aerosol studies have been conducted with cigarette smoke, which has a particularly high level of acute toxicity. For example, animals have been intermittently exposed to boluses of smoke with CO levels of 60 g/m^3, nicotine at 4 g/m^3, and particulates near 50 g/m^3 (Brazell et al, 1984). The overall durations of such exposures are relatively short. Because the gunsmoke is expected to be less acutely toxic (2000 ppm maximum CO levels after final dilution in this system), the exposures are expected to be several hours in duration. Thus, it seems likely that restraints for normally docile beagle dogs would be required. For monkeys, it is expected that extremely durable and fairly sophisticated restraint systems would be required.

5.7.3 Non-Inhalation Toxicological Study Considerations

A number of in-vivo and in-vitro bioassays exist for the toxicologic evaluation of complex organic mixtures, including those from combustion processes (Griest, et al, 1981, Whitmyre, 1981, Casto et al, 1981, and Gray et al, 1987). These range from bacterial mutagenicity assays to skin painting tumorigenicity studies on live mice. For the in-vitro studies as applied to fresh gunsmoke exhaust, the exposure of biological media seems relatively straightforward. It would seem a simple matter to route the exhaust at whatever dilution level required through a controlled temperature chamber containing the exposure plates. The only modification required of the CDS would be to provide the dilution air conditioned to a temperature and relative humidity such that when it was mixed with the exhaust, it would be at a state which is compatible with conditions in the environmental chamber.

For those studies which would require a gunsmoke condensate or condensate extract, such as mouse skin painting, the collection method and sample work-up prior to biological testing is more complex. Either of two approaches seem valid. The specific tack taken would depend on the particular needs of the bioassay. One approach generates condensate by first producing the exhaust and then collecting it in a cryotrap. Such a procedure has been employed for the generation of large quantities of cigarette smoke condensate (Patel, 1980), and is described in detail in that manuscript. Briefly, multiple cigarettes are burned simultaneously, and the smoke aerosol is drawn through a series of cryogenically cooled traps containing spun Teflon filament to increase the contact area. The sample processing required to remove the condensate from the traps is quite involved, and because of that reason, cigarette smoke condensate production is usually limited to relatively large batches. Also, in the process of stripping all of the solvent used to wash the condensate from the traps, many of the more volatile components are removed. Additionally, a large fraction of the initial amount of material passing into the trap is not collected very efficiently, as the effective surface area of the trap is fairly low until particulate matter condenses and increases the area. Another approach for generating smaller batches of an extract for chemical or biological studies involves the use of filtration followed by extraction. In this approach, particulates and some of the less volatile vapor phase constituents are retained, and none of the material produced initially is lost. Additionally, a given filter type will have the same vapor adsorptive and filtration properties from run to run. Consequently, the material ultimately extracted is more well defined than that produced from cryotrapping. A typical 8"x10" filter can be loaded with 500 - 1000 mg of particulate matter, and extracted with a relatively small amount of solvent. A relatively simple way of collecting the exhaust would be to place a high flow vacuum motor, capable of drawing several m^3/minute through a filter, immediately downstream of the proportioning valve of the CDS. Alternatively, to minimize sample collection time, such a system would be installed upstream of the proportioning valve. However, this would require "breaking into" the overall CDS, which would be a more complicated procedure. Another alternative would be to place the filter at the exit of the high volume exhaust.

5.8 PROJECTILE CONTAINMENT

On first consideration, the image of a high powered rifle or cannon projectile having to be stopped or contained in a relatively small area seems incongruent with conventional and safe laboratory operations. In fact, a number of studies have been reported in which small guns or rifles have been enclosed in manners similar to those proposed, the round fired, and the projectile contained in a safe manner (Stiefel and Hody, 1970; Snelson et al, 1983). There are also a large number of facilities around the United States which fire larger projectiles in a laboratory or semi-laboratory setting (Trifiletti, 1988, personal communication; von Halle, 1988; Erickson, 1982). Some projectiles weighing as much as 2 kg are fired in a laboratory. The major difference between the facilities used for these studies, and the facility whose criteria are being discussed in this document, is that in the former, projectiles are fired on an intermittent basis. In the proposed facility, the 30 mm cannon could conceivably be fired as frequently as once per minute for an 8 hour day. The only practical effect of this frequent firing is that projectile containment systems would have to be replaced more frequently and that gun barrel wear would be increased. Depending on the frequency of the firing and the size of the projectile, the replacement activities may be required at a sufficient rate so as to delay animal inhalation exposure schedules unless work was performed on weekends or after normal working hours.

Judging from a review of the literature and discussions with experts and manufacturers, there appear to be several systems employed for projectile containment. Five are briefly discussed below as examples of those types which are expected to function optimally. However, other approaches exist which might also be effective.

Snelson et al (1983) employed a centrifugal bullet catcher. However, the investigators found that the metal aerosol generated from the impact rapidly migrated into the particulate sampling region. This would confound both the chemical and biological evaluation studies, and thus is not recommended.

Water-filled tanks represent an approach which is commonly used for small arms firing. The projectile is directed into a tank filled with water where its energy is expended. The Detroit Armor Corp., of Schaumberg, Illinois, manufactures a typical system, a Model AJ-850 Ballistics Projectile Recovery System. This device is designed to capture bullets sized up to a 7.62 mm round (M-60 equivalent) fired from an angle into the tank. In order to accomplish this in the gunsmoke facility without modifying the tank, it would be necessary to tilt the entire generator and CDS at an angle above the tank. This would be impractical. Another approach would be to use a deflector plate to direct a horizontally fired shot into the tank. This is the same approach as is used on many indoor firing ranges.

Another approach which seems particularly suited to stopping the projectiles from the small rifle generator system is the use of rubber screen bullet trap. Detroit Armor manufactures a Model RC-3500 Rubber Composite Bullet Trap, designed to withstand all shotgun and rifle ammunition up to 3500 feet per second muzzle velocity. The bullet trap consists of multiple layers of 3/8" to 1/2" thick rubber lammels hanging from an overhead steel supporting frame in a pattern designed so that all shots fired into it are stopped. A self-healing rubber screen is hung in front of the lammels so that the chance of ricochet is minimized. The specifications for this system claim that one square meter of the unit can accommodate approximately 50,000 rounds of 9 mm ammunition before replacement is required.

One of the most popular approaches to bullet catching is the use of a sand trap. This approach has been used for small arms projectile containment (Stiefel and Hody, 1970; Snelson, et al, 1983) up to at least 30 mm weapons (Trifiletti, 1988,). This is probably one of the simplest systems to employ. Essentially, the projectile is fired into a pile of sandbags, the ultimate size of which is determined by the size of the projectile which must be stopped. As the bags are ripped and the sand lost, fresh bags are added to the top of the pile. The sand trap has several advantages, the primary ones being that it is inexpensive, it is essentially self-healing, and the opportunities for ricochets are limited.

Finally, ablative steel plates have been used for larger sized projectiles. For example, this type of system is used routinely for stopping the projectiles from 20-mm guns at the University of Dayton Research Institute (Hanchak, 1987; Bless, 1982). The steel plates are surrounded by stacked railroad ties so that steel fragments from the plates or the projectile are stopped before they leave the containment area. Such a system is also employed with 101-mm gun at Lawrence

Livermore National Laboratory to stop 1 kg projectiles fired at speeds up to 2 km per second (von Halle, 1988; Erickson, 1982). The plates are replaced as they are worn down. One of the primary advantages of this type of system is that the plates can be easily moved if they are hung from a steel chain and pulley assembly. Since the path of the projectile in the gunsmoke exhaust generation facility will be fixed, it will be necessary to move the bullet trap slightly with successive firings, so that the same place on the trap is not impacted continuously. This seems easy to accomplish with a series of steel plates hung from chains, or the commercially available rubber curtain bullet catcher. With the sand trap system, there appear to be two alternatives. The first is to mount the entire trap on a mobile platform. The platform would then be shifted slightly from time to time, in order to shift the point at which the bullet impacts the trap. An alternative approach would be to interpose a steel plate into the projectile path at a slight (and adjustable) angle. The bullet would then strike the plate and be directed at an angle into the sand trap. The point at which the bullet enters the sand would be dependent on the angle at which the plate was tilted. Such an adjustable system may be more complex than is required, given the self-healing nature of the trap.

For the gunsmoke generation facility, two systems are recommended. First, for the small arms firing, the commercially available rubber curtain appears to be the most cost effective approach, provided that the point of impact of the bullet on the curtain can be shifted by changing the position of the trap relative to the projectile path. For the larger gun system, the sand trap appears to be the easiest approach. It is inexpensive, and seems to provide for less chance of bullet ricochet.

5.9 NOISE ABATEMENT

A potentially significant problem in developing an exposure system involving firearms is the noise associated with the discharge. This is a problem not only for the animals being exposed but also for the personnel operating the system. The entire system will need to be rather heavily insulated or soundproofed. In addition, the room within which the generation system is located should also be insulated. This would seem to be best accomplished by insulating both the inside and outside surfaces of the over-chamber in which the generator and CDS will be situated (see Section 5.10.1 below). Such insulation would be accomplished through the use of an acoustic foam, such as Sonex (Illbruck, Minneapolis, MN). Noise levels in areas subject to routine access by personnel would be insulated so as to be in compliance with OSHA Specification 1910.95, limiting noise exposure to less that 90 dBA for 8 hours/day, and/or 115 dBA for 15 minutes per day. If personnel were required to be inside the over-chamber during firing, hearing protection would be worn as a routine precaution.

The animal containment system will be situated in a room adjacent to the over-chamber and control and analytical instrumentation area. With present acoustical materials it should not be difficult to confine the noise generated to the system itself, however animals actively being exposed to the exhaust components may be exposed to the noise by conduction of the sound through the system components or the exposure atmosphere itself. Care must be taken to ensure that these noises are not at a high stress level. Even low intensity sharp noises that are accompanied by another insult such as the components of the gunsmoke can cause alterations in breathing patterns, which may confound interpretation of the observed effects. It will likely that some decoupling of the ducts leading to the exposure chambers will be necessary. This would be accomplished by adding baffles to the ducts, and changing the material of the duct work at one or two points between the proportioning system and the exposure chamber.

5.10 SAFEGUARDS AND SECURITIES ISSUES

While military personnel may be accustomed to the presence and firing of guns, it seems likely that the scientific, technical, and support personnel associated with a gunsmoke characterization facility will be more apprehensive about proximity to a weapon. That will be especially the case when dealing with the 30 mm system. Therefore, the safeguards which might be adequate at a military facility will probably not be perceived as being so at a civilian facility, either government or private. Thus, in order to place the operation at an institution which has the scientific staff necessary to conduct the appropriate studies, it will probably be necessary to "over-design" the safety systems. There are three general areas of concern: catastrophic failure of the gun generator system, security of the gun and ammunition, and selected siting considerations. These are discussed briefly below.

5.10.1 Catastrophic Failure of the Gun System

It seems likely that the entire generation, collection/distribution, and projectile containment system will have to be designed to handle a worst-case scenario for a catastrophic failure. This could take the form of a projectile missing or completely penetrating the bullet catcher, or the rupture of the breech or gun barrel during firing. Probably the most straightforward manner of dealing with this possibility is to place the gun generator and the components of the CDS in a small concrete room or over-chamber, and line the walls of the room with steel plate sufficiently thick to retain an errant projectile. All of the control systems, such as the monitoring instrumentation, the chemical characterization systems, and the proportioning system would be located outside the chamber, for ease of maintenance. Access to the chamber would be via locked doors, probably one near the breech assembly and another set of doors near the end of the bullet catcher, for ease of replacement of the sandbags. Walls of the chamber would be lined with sound absorption material, as described above. Personnel would not be permitted in the chamber during firing, except under special circumstances. To deal with a misfire, a protocol would have to be established to delineate how much time must pass before entering the chamber and removing the live round, and who would perform the task. A mobile magazine, designed to contain a round, should be located inside the chamber, in order to minimize required handling of the misfired round.

5.10.2 Gun and Ammunition Security

Depending on the size and exposure protocol of an inhalation exposure study, the gunsmoke generator could consume as much as 1000 rounds of 30 mm ammunition per day (2 rounds per minute for 8 hours). As a result, significant storage capability should exist near the laboratory where the studies are being conducted. Standard ammunition safes are likely to be adequate for short term storage. During a sub-chronic exposure study, it may be necessary to store a month's worth of ammunition somewhere at the institution where the studies are being conducted. In such a case, storage bunkers would seem most appropriate. However, the ammunition must also be considered as a source of high explosives, and it may be that some institutions will require that the material be stored according to criteria associated with explosives. In some cases, these may be more stringent than those for ammunition. Clearly, standard safety precautions should be followed, including use of spark-free tools near the storage facility, no smoking, lightning protection on buildings, etc. It is also likely that an institution conducting such studies will require an accounting of the ammunition, much like that which is used for dangerous or prescription drugs. Large research institutions, such as those most likely to conduct such studies, presumably will have explosives or ammunition storage and handling protocols in place. If not, these can easily be obtained from those that do.

A gun, rifle, or cannon in a facility where ammunition for it is also present represents a potential target for criminal activity. In order to minimize this risk, the gun should be locked in place, perhaps in such a manner that two individuals must be present to move it. Clearly, anything which has been assembled can be disassembled, but the point of the locking mechanism is to require a greater length of time to perform such a task. Access to the laboratory should be limited. Keyed locks are adequate. There needs to be no special security beyond that which most government or corporate research and development institutions would normally maintain.

5.10.3 Siting Considerations Related to Safety Issues

The requirement to store significant quantities of ammunition is likely to limit the siting of a gunsmoke generation facility to an institution which has either pre-existing bunkers or the land on which to construct them. Because of the complexity and interdisciplinary nature of the chemical and toxicological characterization studies to be conducted, it seems most likely that facility would be located at a large private or government research institute. There exists a significant possibility that a candidate institution would also have either strategic nuclear materials or chemical and/or biological agents on its premises. In such a case, it is anticipated that some bureaucratic resistance to placing a live gun in a nearby location would be encountered, due to terrorism concerns. However, the institutions which have such materials regularly present will have such elaborate security networks, both from an organizational and a physical plant standpoint, that weapons and ammunition would already be present at the facility. Thus, the added security burden of an additional M-16, M-60, or 30 mm cannon seems minimal.

5.11 DISPOSAL OF SPENT EXHAUST ATMOSPHERES

Disposal of the gun emissions should not be a difficult problem. Solids will not be at high concentrations nor will the gases be exceptionally hazardous. We conclude that normal laboratory hood filtering systems with a HEPA final filter will serve well for solid clean up. However to prevent too frequent changes of those filters, a high capacity filter such as the bag type filter as manufactured by the Cambridge filter Corp. (Model 3Z95) would be effective in particulate cleanup. The filtered gases should be safely diluted by the normal hood air flow and then liberated through a suitable stack.

5.12 TECHNICAL STAFF REQUIREMENTS

Assuming that the gunsmoke generation and CDS facility is developed by appropriate personnel, the staff to run the system itself would be fairly limited in number. Probably one half-time BS/MS level chemist and one full time chemical technician would be all that would be required. However, the training of these individuals would have to be highly specialized. The BS/MS chemist would need to have a unique blend of both mechanical skills and training in analytical chemistry. The gun and the CDS are essentially mechanical systems, thus the requirement for significant mechanical training. However, the system is run by an analytical chemical instrument, and the routine monitoring systems are similar. The technician that performs the routine cleaning, maintenance and inspection of the system should be well versed in gun and cannon operation. This individual would be responsible for both routine operations and initial trouble shooting of the gun system. One approach to staffing such a position would be for it to be filled through a series of one-year assignments on a temporary duty by an enlisted man from an Army armament unit or other appropriate service. This would only be practical if the facility was located near a military base. Overall costs of relocation and salary might be lower for such an individual that those required to support a permanent staff technician position at a large research institution.

Of course, the generator is of little interest without the chemical and/or toxicological evaluation capabilities. As discussed previously, operations or staff generic to toxicology facilities will not be discussed in this report. Suffice it to indicate that any toxicology studies would have to be conducted with appropriate personnel, which would include toxicologists, pathologists, veterinarians, and animal handlers. The staff required to conduct chemical evaluation studies would be dependent on the size and degree of sophistication of the study to be undertaken. For example, the staff needed to perform analyses of the reactive gases (which are monitored in real time by instrumentation), the total particulate mass, and metallic constituents only in the exhaust would be considerably smaller than that required to perform a complete characterization of the trace polynuclear aromatic hydrocarbons (PAH's) and nitro-PAH's in the particulate phase of the exhaust. The instrumentation required for the latter efforts would also be more sophisticated and expensive. The authors would expect that each institution which might be a candidate site would have a somewhat different approach to staffing for a given project. And the staff would vary, depending on the nature of the project. It seems reasonable to indicate that the thorough characterization of the chemical composition would require a reasonably talented staff, ranging in training from chemical technicians to Ph.D level personnel, with access to sophisticated analytical instrumentation.

One potential approach to simplifying the siting requirements for the facility is to locate it at a site where toxicological studies can be performed, and to send those samples which require more sophisticated analytical effort to another more appropriate analytical chemical institution. This approach has the advantage of expanding the number of institutions which could perform the toxicology studies (since they would not have to be well suited to perform the chemical studies as well). However, it has the disadvantage of taking the chemical sampling operation and the real-time instrument monitoring out of the control of the professional staff which is most capable of performing those tasks. Clearly, the decision of where to site the facility and how to ultimately design and conduct both chemical and toxicological studies will be a complex one.

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Appendix A

Suggested Suppliers for Selected System Components

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Suggested Suppliers for Selected System Components

Component	Description
CO Analyzer	Beckman Model 865 - Dual Beam Non-Dispersive Infrared Analyzer, dual ranges of 0-100 and 0-1000 ppm. Rosemount Analytical Division Rosemount Incorporated La Habra Operations 600 South Habor La Habra, CA 90631
Automatic Controller	Electronic Microprocessor Based 3-Mode Controller with fully adjustable proportional-integral-derivative (PID) action. Leeds & Northrup Electromax V, LFE Model 2002 or equal. Leeds & Northrup Co. Div. General Signal North Wales, PA 19454 LFE corp. Process Control Division 55 Green Street Clinton, MA 01510
Electro-Pneumatic	D.C. Current to Pneumatic Pressure Transducer, Transducer Leeds & Northrup, Cat. No. 10970 I/P Converter, Bellofram Type 1000 I/P Converter or equal. Leeds & Northrup Co. Div. General Signal North Wales, PA 19454 Bellofram Corp. 30 Blanchard Road Burlington, MA 01803
Proportioning Valve	Three Way Globe Proportioning Control Valve, all stainless construction with pneumatic proportioning operator. DeZurik Model GTW (1753). Assumed to be 2" line size or less. DeZurik Corporation Division of General Signal 250 Riverside Avenue Sartell, MN 56377

Firing Programmer	Custom designed and fabricated but based on a commercially available programmable logic controller (PLC) such as Texas Instruments Model 510 or Allen-Bradley SLC 100. Texas Instruments Industrial Controls Div. Johnson City, TN 37605 Allen Bradley, Inc. Milwaukee, WI 53204
Valve Position Sensor	Miniature Retro-Reflective Optical Sensor Assembly Utilizing Infrared Source/Sensor System. Skan-A-Matic Type 551101. Skan-A-Matic Corp. Route 5 West Elbridge, NY 03077
4" Knife Gate Valve	All stainless steel body and gate with spring return and pneumatically operated. Response time under 2 seconds. DeZurik, Inc. Model GS 4-L1-S2-C-M-LCGC6-DXX037 Price: $937 DeZurik Corporation Division of General Signal 250 Riverside Avenue Sartell, MN 56377
6" Knife Gate Valve	All stainless steel body and gate with spring return and pneumatically operated. Response time 4 seconds. DeZurik, Inc. Model KGS-6-L1-S2-C-M-LCGC10-DXX037 Price: $2162
2" 3 Way Globe	Stainless steel, pneumatic operator Control Valve DeZurik Figure GTW-1753 Price: $4340
High Pressure Valve	Whitey SS-6NBF6-96NC 0.250" orifice air operated Spring return, normally closed 6000 PSI operating pressure, 20000PSI burst pressure 1 sec. operating time in either direction. Whitey Company 318 Bishop Road Highland Heights, OH 44143

Ball Valve Corporation:	Ball valve, all stainless steel/teflon construction with spring return. Gemini 1" Mdl #76-6-RT-6-412SR-MC3-410 Price: $299 2" Mdl #76-6-RT-6-422SR-MC6-420 Price: $538 Gemini Valve, Inc. Otter Court Raymond, NH 03077
Iris Diaphragm Valves	8" valve standard with polyurethane coated nylon diaphragm. Teflon coated metal parts with pneumatic operator. KEMUTEC Inc., Model G8, Operating time of valve 2.5 seconds in each direction. Price: $2554 KEMUTEC, Inc. Bristo, PA
Tedlar Bags	Gas Sampling Bags SKC, Inc. 334 Valley View Road Eighty Four, PA 15330
Bag Filter	Fiber glass filter, bag type, 12"X24'X29" five bags parallel, 48 sq. ft. filter surface, 93-97% efficient against atmospheric dust. 30 gram/sq.ft. capacity against AFI dust. Cambridge Filter Corporation, Filter Model 3Z95. Cambridge Filter Corporation P. O. Box 1255 7645 Seventh N. Road Syracuse, NY 13201

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